# OUTLINES
# OF COSMIC PHILOSOPHY

IN FOUR VOLUMES

VOLUME II

# OUTLINES OF COSMIC PHILOSOPHY

## BASED ON THE DOCTRINE OF EVOLUTION, WITH CRITICISMS ON THE POSITIVE PHILOSOPHY

BY

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WITH AN INTRODUCTION BY JOSIAH ROYCE

*L'univers, pour qui saurait l'embrasser d'un seul point de vue, ne serait, s'il est permis de le dire, qu'un fait unique et une grande vérité.* — D'ALEMBERT

Καὶ τὸ ὅλον τοῦτο διὰ ταῦτα Κόσμον καλοῦσιν, οὐκ ἀκοσμίαν. — PLATO

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# OUTLINES OF COSMIC PHILOSOPHY

## PART I

### PROLEGOMENA (*continued*)

"Quare speculatio illa Parmenidis et Platonis, quamvis in illis nuda fuerit speculatio, excelluit tamen: Omnia per scalam quandam ad unitatem ascendere." — BACON.

"Das schönste Gluck des denkenden Menschen ist das Erforschliche erforscht zu haben, und das Unerforschliche ruhig zu verehren." — GOETHE.

# CHAPTER VIII

## ORGANIZATION OF THE SCIENCES[1]

THE results obtained in the course of the preceding inquiry have added depth and precision to our conception of the Scope of Philosophy. In coming to look upon all phenomena as manifestations of a Power unknowable in itself, yet knowable in the order of its phenomenal manifestations, we have virtually come to declare that the true business of philosophy is the determination of the order of the phenomena in which this omnipresent Power is manifested. And thus we arrive by another road at the very same definition of Philosophy which was previously given; and we see that the progress of deanthropomorphization, while leaving the religious attitude of philosophy entirely unchanged, has at the same time precisely limited its scope in making it the Synthesis of the general truths of science into a system of universal truth. We have next to inquire, as preliminary to the construction of such a Synthesis, into the manner in which the different orders of scien-

[1] [See Introduction, § 14.]

tific truths are to be grouped for the purposes of our philosophic construction. In short, we are brought face to face with the problem which also occupied Comte next in order after the question of deanthropomorphization; we have to deal with the classification of the sciences. And as in the preceding chapter, we shall endeavour, while adversely criticising the Comtean theory, to elicit results which are both true and available for our subsequent inquiries.

Comte begins by distinguishing two kinds of natural sciences — the one kind abstract and general, having for their object the discovery of the laws to which the various orders of phenomena conform, in all conceivable cases; the other kind concrete, special, descriptive, consisting in the application of general laws to the natural history of the various objects actually existing in the present or past. There is nothing difficult, or even novel, in this distinction, since it corresponds very nearly with that which is ordinarily drawn in scientific treatises between dogmatic physics and natural history. We shall see the difference very clearly by comparing general physiology on the one hand with zoölogy and botany on the other. The one formulates the general laws of life, whether considered in equilibrium or in the process of development; the other merely enumerates the conditions and mode of existence of each particular species of living bodies. Similar is the contrast between chemistry and mineralogy, of which the latter science is evidently founded upon the former. In chemistry we consider all possible combinations of heterogeneous molecules, in all imaginable circumstances; in mineralogy we consider only the particular combinations which are found realized in the actual past or present constitution of the terrestrial globe, under the influence of special sets of conditions. A circumstance which well illustrates the difference between the chemical and the mineralogical point of view, although the two sciences deal with the same objects, is, that a large proportion of the facts contemplated in chemistry have only an artificial or experimental existence. So that, for example, a body like chlorine or potassium may possess great importance in chemistry by reason of the extent and energy of its reactions and its affinities; while in mineralogy, on the other hand, it may be of little importance, because it is but seldom concerned in producing the natural rearrangements of molecules which it is the business of mineralogy to explain. And conversely, some such compound as granite or feldspar, which fills a great place in mineralogy, may be of little interest from the chemical point of view.

Of these two kinds of sciences, according to

Comte, manifestly it is the first kind which first needs to be classified and systematically studied in its doctrines and methods. The scientific study of concrete physics presupposes the scientific study of abstract physics. For example, the study of the geologic development of the earth, when prosecuted in the most comprehensive manner, requires not only the previous study of physics and chemistry, but also some previous knowledge of astronomy and physiology. And similarly the scientific study of oceanic and atmospheric currents — which, in the present chaotic state of our nomenclature, we characterize variously as meteorology, or climatology, or include under physical geography — demands a preliminary acquaintance not only with mechanics, chemistry, and all the branches of molecular physics, but also with astronomy, since climatic rhythms depend upon the inclination of the earth's axis to the plane of the ecliptic, and more remotely upon the variations in that inclination known as precession and nutation. It is for this reason that concrete physics has made so little progress down to the present day, since it could begin to be rationally studied only after all the branches of abstract physics had assumed a distinctively scientific character. While, conversely, as soon as abstract physics has been completely organized, the study of concrete physics becomes merely the detailed application of general principles already established.

From these considerations Comte concluded that his Positive Philosophy might be founded upon a thorough organization of the doctrines and methods of the abstract sciences alone. The problem first in order was to arrange these sciences in a natural series. The end to be kept in view, in this encyclopædic labour, is to arrange the sciences in the order of their natural succession and mutual interdependence; so that we may study and expound them one after the other, without ever being led into a zigzag or circular course of study and exposition. It should be mentioned here at the outset, that Comte did not regard such an end as strictly attainable in all its rigorous precision. He tells us expressly that however natural and however logically serviceable such a classification may be, it must always and necessarily contain something that is arbitrary, or at least artificial, in its arrangements. This, as he clearly saw, must ever result from the very richness and complexity of Nature, which refuses to be analyzed and partitioned off into distinct provinces, save provisionally for convenience of study. In his Introduction he reminds us that so few as six fundamental sciences will admit of seven hundred and twenty different arrangements; and that in behalf of each of these arrangements very likely something might be said, since even in the various classifications already proposed, the same science which one places at the beginning of the scale is by another placed at the end.[1] Nevertheless there is one series which is clearly indicated by the decreasing generality and simplicity of the phenomena with which the respective sciences are concerned. And this is the order which Comte adopts, primarily on account of its logical convenience. He begins with the most simple and general phenomena, to proceed step by step to those which are most complex and special.

Proceeding upon this principle, we are confronted at once by two grand divisions of phenomena, inorganic and organic. There is no difficulty in deciding which of these to study first. The more general and simple phenomena of weight, heat, light, electricity, and chemism, are manifested alike by not-living and by living bodies; whereas the more special and complex phenomena of life are manifested, of course, only by the latter. Therefore the science of inorganic phenomena must precede the other. We can study thermal radiations and chemical reactions without taking vital forces into the

[1] Later in life Comte, no doubt, came to look upon his classification as complete and final. And so it appears to be regarded by his disciples, who are deaf to all the considerations which impeach it.

account; but we cannot study living organisms without appealing to physics and chemistry at every step.

In the science of inorganic phenomena a somewhat less obvious principle of division next presents itself. Inorganic physics may be divided into celestial and terrestrial physics; of which the first treats only of gravitative force as manifested in the relatively simple phenomena of the mutual attractions of the heavenly bodies; while the second treats not only of gravitative force as manifested throughout relatively complex terrestrial phenomena, but also of the molecular forces, cohesion and chemism, and of the modes of undulatory motion called sound, heat, light, magnetism, and electricity. This second division may be again subdivided into physics proper and chemistry. The first treats of those changes in which the relative positions of the molecules of matter are altered homogeneously, resulting in increase or decrease of volume, or other change of physical state; while the second treats of those changes in which the relative positions of molecules are altered heterogeneously, resulting in the production of new compounds and new affinities. Of these two sciences, manifestly physics should be first studied. We can to a certain extent generalize the laws of reflection and refraction, condensation and rarefaction, without help from chemistry; but we cannot proceed a step in chemistry without appealing to physics.

Turning now to organic phenomena, we perceive that living beings may be studied either individually or collectively. In the first case we generalize the laws of nutrition and reproduction, of muscular contractility and nervous sensibility. This is the province of biology, a science which according to Comte is of itself competent to include all the phenomena presented by vegetables and by the lower animals, as well as all those presented by individual man. But in the case of man, the aggregation of individuals gives rise to an entirely new class of phenomena produced by the reaction of individuals upon each other. To generalize the laws of this class of phenomena is the business of sociology, which is thus manifestly the most complex and special of the sciences.

According to Comte, this disposes of all the fundamental abstract sciences except mathematics. This science he places first of all, the phenomena of number and form being universal, and capable of generalization without reference to other phenomena.

Thus we have the hierarchy of the positive sciences arranged in the following order: —

I. Mathematics.
II. Astronomy.
III. Physics.

IV. Chemistry.
V. Biology.
VI. Sociology.

In each of these sciences there are several subdivisions, which Comte endeavours to arrange, whenever it is possible, according to the same general principle of convenience. In mathematics he places algebra before geometry, on the ground that we can study number by itself, but in order to study form we must make use of sundry laws of number; and for a similar reason, mechanics, which involves time and motion, is placed subsequent to the other two. In physics, barology, or the general doctrine of weight and pressure, is placed first, as nearest akin to astronomy; and electrology is placed last, as nearest akin to chemistry. The intermediate branches, acoustics, optics, and thermology, would now be ranked in the order in which I have named them; but Comte ranked thermology first, probably because of the enthusiasm aroused in him by his friend Fourier's achievement in bringing the general doctrine of thermal expansion and contraction so thoroughly under the sway of mathematical analysis. In biology, anatomy, or the study of structure, is placed before physiology, or the study of function; and the study of the vegetal or nutritive functions precedes that of the animal or nervo-muscular functions. In sociology, the study of equilibrium, or the conditions essential to order, is ranked before the study of the laws of progress as generalized from history.[1]

It will be observed that in this scheme no special place is assigned to psychology. This is an omission quite in keeping with Comte's general conception of the scope of philosophic inquiry, from which the observation and analysis of states of consciousness are purposely omitted altogether. This omission will best be criticised and characterized later on, when in the course of our philosophic synthesis we shall have arrived at the discussion of the relations of the phenomena of mind to the phenomena of life.[2] Meanwhile, merely noting this serious omission, we may observe that the classification just sketched is so fascinating in its simplicity, and so manifestly convenient for many practical purposes of research, that at first it seems almost a pity for criticism to invalidate it. Its leading features appear to speak for themselves, to carry their own recommendation with them,

[1] In a future chapter, it will appear that the proper arrangement is just the reverse of this, no sound theory of social equilibrium being attainable until the laws of progress have been generalized from history, with the aid of biology and psychology. Here, as in many other cases, Comte's error was due to his imperfect comprehension of the principle of Evolution.

[2] See below, Part II. chap. xiv.

to characterize this classification as the best which, with our present resources, it is possible to frame. And, indeed, if we compare it with some of the most ambitious preceding classifications, such as those of Oken and Hegel, or even with the less pretentious but more useful systems of D'Alembert, Stewart, Ampère, Geoffroy St. Hilaire, and Cournot, its superiority is at once apparent. The arrangement seems so natural and obvious that it has not unfrequently been characterized by able critics as "just the sort of classification that would naturally arise in any reflecting mind on a review of the subject." We should not forget, however, that it never had arisen in any of the reflecting minds which reviewed the subject previous to Comte.

But Comte, who viewed everything in a historical light, intended that his classification should be something more than a convenient plan for arriving at philosophic generality through the study of the separate abstract sciences. He regarded it also as a kind of philosophic tableau or conspectus of the progress of the human mind from anthropomorphic toward scientific conceptions of natural phenomena. According to him, the order in which he arranged the sciences was the order in which they had respectively been constituted as sciences, — in which they had passed from the theological or metaphysical into the scientific stage. Thus mathematics, he tells us, has been a science, in the strict sense of the word, from time immemorial; but he omits to tell us that pure mathematics, dealing solely with number and form, and not involving conceptions of force, *could* never have been in the theological stage. It was only the phenomena of force which to primitive men must have seemed to require an anthropomorphic explanation. The action of the human will, by the analogy of which external events were explained, may be a mechanical, but it is not a geometrical or algebraic phenomenon. When we come to mechanics, there is room to construct volitional explanations. Nevertheless in mechanics there are so few traces of such explanations, since the dawn of history, that Comte thinks it may have always been a positive science; and he quotes approvingly Adam Smith's remark that nowhere do we ever hear of a god of Weight. Such a god, however, had there ever been one, would have been a generalized deity, belonging to a comparatively advanced system of polytheism; and though we are entitled to infer from this that the earliest generalization of the phenomena of weight was a scientific and not a theological generalization, we are not entitled to infer that in the primeval fetishistic period, before the phenomena had been generalized at all, they were not supposed to be due to volition. It is one of the unfortunate results of Comte's use of the term "theological" to characterize this primitive philosophy, that we are apt to think it necessary to seek for signs of a deity when examining the so-called theologic epoch. The idea of a god distinct from the phenomenon was, however, a polytheistic, not a fetishistic idea: it was the result of much abstraction and generalization. Fetishism endowed the particular object itself with volition. And such being the case, I am inclined to believe that many even of the simplest mechanical phenomena may have been originally explained as due to the free will of the objects concerned.[1] However this may be, there can be no doubt that mechanical conceptions ceased to be anthropomorphic at a very early date, and that statics, one branch of mechanics, is the oldest of the sciences, outside of pure mathematics.

If now we consider the three great branches of inorganic physics, we find abundant records of a time when the heavenly bodies were supposed to be intelligent creatures, and were worshipped as such. Even in the enlightened age of Perikles, and in the most advanced community then existing, Anaxagoras came near losing his life for asserting that the moon was a mass

[1] See *Myths and Myth-Makers*, chap. vii., "The Primeval Ghost World."

of rocks and not a goddess. Long after monotheism had overthrown these crude interpretations, the planets were still supposed to be the abode of controlling archangels. Even Kepler himself, early in the seventeenth century, was inclined to countenance this opinion, as may be seen from a remarkable passage in his "Harmonices Mundi" (p. 252). It was not until Newton that dynamical astronomy became a positive science. Similarly with the phenomena of terrestrial physics. The electric phenomena of storms, the thermal phenomena of congelation, the optical phenomena of the rainbow and the mirage, have, within the period known to history, been explained anthropomorphically; and, as late as the time of Cardan, echoes were by the unlearned interpreted as the voices of mocking demons, and *ignes fatui* were regarded as malign spirits inhabiting marshes: while in chemistry, both the Arabian alchemists and their European successors — in manipulating some of the more powerful reagents, and especially in the use of explosive or highly combustible materials — believed themselves to be forcing unwilling supernatural agents to execute their purposes. Probably the name "spirits," as employed in modern pharmacy, has had some such anthropomorphic origin.[1]

[1] [The origin of this use of the term spirits is to be found in the Pneuma-doctrine of the later Greek physicians.]

Inorganic physics has by this time become almost entirely free from anthropomorphic conceptions. In the sciences which deal with organic phenomena, however, purely scientific conceptions do not yet reign supreme. Biology and sociology are still infected with metaphysical, and even to a certain extent with theological notions. In biology, for instance, we have the anthropomorphic conception of an *archæus* or vital principle, distinct from the organism, and controlling its molecular processes. Though such a theory would not, at the present day, be defended by any authoritative writer upon this subject, it is nevertheless vaguely present in the popular mind, and exerts a clandestine influence even upon scientific speculations. The metaphysical doctrine of stimulus, so ably criticised by Dr. Anstie in his treatise on "Stimulants and Narcotics," — the doctrine that stimulus is not an increase in the rate of nutrition of the nerves, but a goading of the organism, sure to be followed by a depressive reaction, — is founded mainly upon this antiquated *a priori* conception of a vital principle. To take another instance, colds, fevers, and other diseases are commonly spoken of as entities which "get into the system," and are to be driven out; and imperfectly educated physicians are often heard reasoning upon this mythological assumption; whereas a disease of any kind, scientifically considered, is not an entity, but a disturbance of equilibrium among the interacting functions of the organism. A cancer, for instance, is a modification of structure resulting from a disturbance in the general process of nutrition. Molecules which should normally be deposited here and there throughout the various tissues begin to aggregate over a single limited area, forming a new abnormal tissue, of low vitality; and this new tissue grows at the expense of the organism until death ensues from exhaustion, or, if the wall of a large blood-vessel happens to get encroached upon and disintegrated, death ensues from hemorrhage. So an ordinary fever, in which blood-poisoning does not occur, is the result of an ill-understood alteration in the molecular properties of the blood, one of the chief symptoms of which is the adherence of the blood-corpuscles to the walls of the capillaries. Yet so prevalent still is the personifying habit of thought, that cancers and fevers are spoken of and reasoned about as occult entities, as ugly Things which somehow or other "get into" the blood.

It is hardly necessary to insist upon the prevalence of the metaphysical habit in sociology, where final causes are still sought after, where the doctrine of the "freedom of the will" (or, as it might better be termed, of the "lawlessness of volition") still maintains a precarious footing, and where practical conclusions are constantly based upon the *a priori* doctrine of inherent "rights." Here, too, as well as in biology, even the theological point of view not unfrequently appears. The late war between France and Germany was doubtless the occasion of many prayers to the "God of Battles." The same persons who, in the regular recurrence of the seasons, in the expansion of heated bodies, in the explosion of fulminating compounds, in the darkness caused by an eclipse, in short throughout the entire realm of inorganic phenomena, see nothing but the operations of uniform forces, nevertheless explain diseases, famines, and political revolutions, upon the hypothesis of an overruling Providence extraneous to the Cosmos; announcing, perhaps, the doctrine of a divine judgment upon sin, — which is indeed not a fiction, but the mythologic version of a scientific truth.

Not only (according to Comte) has deanthropomorphization proceeded more rapidly in the simpler sciences than in the more complex ones, but the generalization of causal agencies, of which deanthropomorphization is the result, took place earlier in the former than in the latter. This is to be seen by comparing the dates at which the sciences respectively ceased to be mere aggregations of empirical knowledge, and became founded as sciences, in the strict sense of the word. Thus astronomy, at least in its statical department, was a science in the days of Hipparchos. Physics became a science when Galileo discovered the law of falling bodies. Chemistry became a science, about a hundred and seventy years later, when Lavoisier overthrew the doctrine of phlogiston, and detected the true principles of combustion. Biology did not become a science until the very end of the eighteenth century, when Bichat pointed out the relations between the functions of organs and the properties of tissues. Finally sociology has hardly yet become a science; and many educated persons still regard historical events as happening in no determinate sequence, and stigmatize, as not only chimerical but even impious, any attempt to formulate the order of such events.

Here it becomes desirable to pass from simple exposition to criticism. In the Comtean views above set forth we must of course recognize a large amount of historic truth. There can be no doubt that anthropomorphic conceptions soonest disappear from those departments of science which are earliest constituted and most rapidly developed. Nor can there be any doubt that in a vague and general way the Comtean arrangement represents, or at any rate suggests, the historic order of progression. No doubt mathematics is the oldest of the sciences — as indeed its name curiously hints to us — and sociology the youngest. No doubt the movements of masses, of which astronomy and physics treat, were correctly formulated sooner than the combinations of heterogeneous molecules, which form the subject-matter of chemistry. And no doubt the science of inorganic phenomena as a whole is more complete than the science of organic phenomena. All this must be admitted. Yet if we examine more closely into the matter, we shall discover grave errors in this classification which looked so fair to us on a cursory inspection. We shall notice first that in many points of fundamental importance it does not faithfully represent the order of historic progression; and when we come to inquire into the reason of this failure, we shall find that the classification errs from its very simplicity, that the facts to be arranged are too complex and heterogeneous to admit of any such facile linear arrangement.

In the first place the historical relations between astronomy and physics have been misstated by Comte, and he has marked out the province of physics after a fashion that is, at the present day, completely indefensible. To class together the science which treats of weight and pressure, and the sciences which treat of light, heat, and electricity, and to refer to the whole under the general appellation of Physics, is to prepare the way for statements which are too general to be accurate. In contrasting physics with astronomy, however, Comte is careful to let us know that he intends to designate that physics which deals with the phenomena of moving masses; for he tells us that while astronomy has been a science since the time of Hipparchos, physics first became a science in the days of Galileo. The slightest consideration will show us that this apparent confirmation of Comte's views rests upon a verbal ambiguity. For what portion of astronomical phenomena had been generalized as early as the time of Hipparchos? Simply the statical or geometrical portion, namely, the apparent motions of the planets, the great achievement of Hipparchos having been the construction of the theory of epicycles and eccentrics, whereby to formulate these motions. It is needless to add that all the geometrical data used in making this generalization had been obtained from the previous observation of terrestrial phenomena. And what portion of physics was it which was not generalized till the time of Galileo? It was the dynamical portion, since statics had been erected into a science by Archimedes, who lived just a century before Hipparchos. By comparing the statical part of astronomy with the dynamical part of physics, Comte finds it quite easy to establish the precedence of the former. Unfortunately, such precedence is not what the argument requires, though it is all that can be established. If we compare like orders of phenomena, we shall see at once that it was physics which preceded astronomy. Dynamical astronomy became a science only with the discovery of the law of gravitation; and this law was not discovered, nor could it have been discovered, until after the leading generalizations of terrestrial dynamics had been established. For, as Mr. Spencer observes, "What were the laws made use of by Newton in working out his grand discovery? The law of falling bodies, disclosed by Galileo; that of the composition of forces, also disclosed by Galileo; and that of centrifugal force, found out by Huyghens — all of them generalizations of terrestrial physics. . . . Had M. Comte confined his attention to the things and disregarded the words, he would have seen that before mankind scientifically coördinated *any one class of* phenomena displayed in the heavens, they had previously coördinated *a parallel class of phenomena* displayed upon the surface of the earth."[1]

This criticism is a very incisive one. It destroys this part of Comte's classification not only from the historical, but also from the logical point of view. It shows that the study of

[1] Spencer's *Essays*, 1st series, p. 179. [Library Edition vol. ii. p. 22.]

astronomy depends upon that of terrestrial physics, and should therefore come after, and not before it. In fact the whole science of astronomy, as at present constituted, consists of two portions, — the theory of gravitation and the theory of nebular evolution. The first of these, as we have just seen, is a mere extension to celestial phenomena of certain laws of terrestrial physics. The second depends upon the study of terrestrial phenomena in a yet greater degree, since it involves the knowledge not only of gravitation, but also of radiant heat, and of the conditions of equilibrium of gases and liquids.[1]

If now we compare physics with chemistry, we shall find a similar ambiguity in Comte's results. It is easy to say that chemistry was not organized into a science until toward the close of the eighteenth century, while physics was organized at the beginning of the seven-

[1] I leave this as it stood five years ago, when this chapter was written. The numerous and wonderful disclosures of spectrum analysis, not only giving us unlooked-for information concerning the physical constitution of the stars, but even throwing new light on their movements, make it desirable, perhaps, to enlarge the scope assigned to astronomy in the text. But such a modification of the form of statement would show only the more forcibly how closely the study of astronomy depends on the study of terrestrial phenomena. The greatest step recently taken in science is thus an additional argument against the validity of Comte's conception.

teenth: but what do we now mean by physics? If we mean merely the science which generalizes the phenomena of weight, our proposition is indisputable; but unfortunately it is of little use in supporting the Comtean classification. For Comte, as we have seen, includes under the general head of physics, not only the science of weight, but also the sciences of heat, light, electricity and magnetism, to say nothing of sound. It was incumbent on Comte to show that this whole group of phenomena became scientifically coördinated at an earlier date than the phenomena of chemical composition and decomposition. This, however, it would have been impossible to show. Electric phenomena, the most backward of the group, were not scientifically coördinated until the close of the last century, when Coulomb generalized the laws of electric equilibrium. Strictly speaking, there was no general science of Physics even when Comte wrote the "Philosophie Positive;" and in linking together the allied departments of optics, thermology, acoustics and electrology, he made up what was then an incongruous group, about which it was unsafe to make general statements. In 1842 — the year in which Comte's work was finished — Mr. Grove, by showing that the different allied manifestations of physical force are modes of motion which are convertible into each other, laid the foundations of a general science of Molecular Physics, regarded as a science of vibrations. And in 1843 Mr. Joule, by discovering the mechanical equivalent of heat, gave to the new science a quantitative character. These were the great epoch-making steps, like the steps taken by Newton in astronomy, which founded the science.[1]

It is thus evident that Comte was far from successful in this part of his classification; and considering the state of science forty years ago, it appears impossible that he should have succeeded. He united phenomena which should have been kept separate, and separated phenomena which should have been united. We are now in a position to see that Comte's grand division of inorganic science must be subdivided into Molar Physics, which treats of the movements of masses; Molecular Physics, which treats of the movements of molecules and of the laws of aggregation of homogeneous molecules; and Chemistry, which treats of the laws of aggregation of heterogeneous molecules. And we see, moreover, that astronomy is merely the application of the principles of molar physics (and, in its latest researches, of molecular physics and

[1] [The history of the theory of the Conservation of Energy has been much discussed since this passage was written. It is possible that Fiske would have given, in the light of later researches, credit to Mayer for his share in the great generalization.]

chemistry also) to the study of a special class of concrete phenomena. Such is the logical arrangement; and the only historical parallelism to be found is the fact that theorems relating to masses were reached sooner than theorems relating to molecules.

It would not be difficult to cite other instances in which the Comtean classification is at variance not only with the order of the phenomena classified but also with the order of historic progression. But I prefer to quote from Mr. Spencer a remarkable passage which strikes immediately at the vital point of the theory. Comte's fundamental error was in not recognizing "the constant effect of progress in each class upon *all* other classes; but only on the class succeeding it in his hierarchical scale. He leaves the impression that, with trifling exceptions, the sciences aid each other only in the order of their alleged succession. But in fact there has been a continuous helping of each division by all the others, and of all by each. Every particular class of inquirers has, as it were, secreted its own particular order of truths from the general mass of material which observation accumulates; and all other classes of inquirers have made use of these truths as fast as they were elaborated, with the effect of enabling them the better to elaborate each its own order of truths. It was thus with the application of

Huyghens's optical discovery to astronomical observation by Galileo. It was thus with the application of the isochronism of the pendulum to the making of instruments for the measuring of intervals, astronomical and other. It was thus when the discovery that the refraction and dispersion of light did not follow the same law of variation affected both astronomy and physiology by giving us achromatic telescopes and microscopes. It was thus when Bradley's discovery of the aberration of light enabled him to make the first step towards ascertaining the motions of the stars. It was thus when Cavendish's torsion-balance experiment determined the specific gravity of the earth, and so gave a datum for calculating the specific gravities of the sun and planets. It was thus when tables of atmospheric refraction enabled observers to write down the real places of the heavenly bodies instead of their apparent places. It was thus when the discovery of the different expansibilities of metals by heat gave us the means of correcting our chronometrical measurements of astronomical periods. It was thus when the lines of the prismatic spectrum were used to distinguish the heavenly bodies that are of like nature with the sun from those which are not. It was thus when, as recently, an electro-telegraphic instrument was invented for the more accurate registration of meridional transits. It was thus when the difference in the rates of a clock at the equator and nearer the poles gave data for calculating the oblateness of the earth, and accounting for the precession of the equinoxes. It was thus — but it is needless to continue. We have already named ten cases in which the single science of astronomy has owed its advance to sciences coming after it in Comte's series. Not only its secondary steps, but its greatest revolutions have been thus determined. Kepler could not have discovered his celebrated laws, had it not been for Tycho Brahe's accurate observations; and it was only after some progress in physical and chemical science that the improved instruments, with which those observations were made, became possible. The heliocentric theory of the solar system had to wait until the invention of the telescope before it could be finally established. Nay, even the grand discovery of all — the law of gravitation — depended for its proof upon an operation of physical science, the measurement of a degree upon the earth's surface. Now this constant intercommunion, here illustrated in the case of one science only, has been taking place with all the sciences. . . . Let us look at a few cases. The theoretic law of the velocity of sound, enunciated by Newton on purely mechanical considerations, was found wrong by one sixth. The error remained unaccounted for until the time of Laplace, who, suspecting that the heat disengaged by the compression of the undulating strata of the air gave additional elasticity, and so produced the difference, made the needful calculations and found he was right. Thus acoustics was arrested until thermology overtook and aided it. When Boyle and Mariotte had discovered the relation between the density of gases and the pressures they are subject to, and when it thus became possible to calculate the rate of decreasing density in the upper parts of the atmosphere, it also became possible to make approximate tables of the atmospheric refraction of light. Thus optics, and with it astronomy, advanced with barology. . . . When Fourier had determined the laws of conduction of heat, and when the earth's temperature had been found to increase below the surface one degree in every forty yards, there were data for inferring the past condition of our globe; the vast period it has taken it to cool down to its present state; and the immense age of the solar system — a purely astronomical consideration. Chemistry having advanced sufficiently to supply the needful materials, and a physiological experiment having furnished the requisite hint, there came the discovery of galvanic electricity. Galvanism reacting on chemistry disclosed the metallic bases of the alkalies, and inaugurated the electro-chemical theory; in the hands of Oersted and Ampère it led to the laws of magnetic action; and by its aid Faraday detected significant facts relative to the constitution of light. Brewster's discoveries respecting double refraction and dipolarization proved the essential truth of the classification of crystalline forms according to the number of axes, by showing that the molecular constitution depends upon the axes. In these, and in numerous other cases, the mutual influence of the sciences has been quite independent of any supposed hierarchical order. Often, too, their interactions are more complex than as thus instanced — involve more sciences than two. . . . So complete in recent days has become this *consensus* among the sciences, caused either by the natural entanglement of their phenomena, or by analogies in the relations of their phenomena, that scarcely any considerable discovery concerning one order of facts now takes place without very shortly leading to discoveries concerning other orders."[1]

Mr. Spencer goes on to describe the infinitely complex manner in which the various sciences act upon the advancement of the arts, and are reacted upon by that advancement. He enumerates the vast multitude of arts, involving the knowledge of many distinct sciences, which enter into the economical production of

[1] Spencer's *Essays*, 1st series, pp. 181–183, 214, 215.

such an apparently simple article as a child's calico frock. He shows that the various sciences by turns stand in the relation of arts to each other; and that often the mere process of observation in any one science requires the aid of half a dozen other sciences. But it is needless for me to go on quoting from an essay which is easily accessible, and which should be read from beginning to end by every one who wishes to understand the true character of scientific progress. I prefer to add an illustration or two, suggested by the progress of science during the nineteen years that have elapsed since that essay was published; and to observe how Kirchhoff's discoveries in spectrum analysis — rendered possible only through a great advance in chemical knowledge — have reacted upon astronomy, enabling Mr. Huggins to determine the proper motion of Sirius, and consequently, by putting it in our power to ascertain the motions of all those stars which, moving directly towards or away from us, yield no parallax, have laid the foundations for a general theory of sidereal dynamics, to be further elaborated in the future. Or to take a still more striking instance, let us remember how Adam Smith's elucidation of the principle of "division of labour," in sociology, suggested to Goethe the conception of a "division of labour" in biology, and thus heralded Von Baer's magnificent discovery that organic development is a progressive change from homogeneity to heterogeneity of structure. And let us note how this discovery in biology has lately reacted upon all preceding departments of investigation, strengthening the nebular theory in astronomy and the theory of the progressionists in geology; and thus ultimately reacting upon our philosophy by giving us, for the first time, a scientific doctrine of the evolution of the physical universe.

Enough has been alleged to prove that the Comtean view of the progress of science fails to account for more than a limited portion of the facts of that progress. Instead of the sciences aiding each other, with few and unimportant exceptions, only in the hierarchical order in which Comte has placed them, we perceive that they have continually been aiding each other in all directions at once. The more complex sciences have all along been assisting the simpler ones, and these have often been delayed in their progress for want of the assistance which the former have ultimately furnished. There has, therefore, been no such thing as a progressive evolution of the sciences in a linear order; but there has been a consentaneous evolution, in which the advance of each science has been a necessary condition of the advance of all the others.

It thus appears that Comte unduly simplified the problem. His classification well enough expresses the order of development of the sciences, in so far as their development has depended merely on the relative simplicity or complexity of the phenomena with which they have had to deal. It rests upon the assumption that, with few and unimportant exceptions, the progress of generalization has been from the simple to the complex. Now this is not the case. The progress of generalization has indeed been partly determined by the relative simplicity or complexity of the phenomena to be generalized (and this fact accounts for the considerable amount of truth which the Comtean doctrine contains); but it has been also determined by several other circumstances. In the chapter on "Laws in General" to be found in the first edition of "First Principles," but omitted in the revised edition,[1] Mr. Spencer has called attention to some of these circumstances. He reminds us that not only are phenomena early generalized in proportion as they are *simple*, but also in proportion as they are *conspicuous* or obtrusive. "Hence it happened that after the establishment of those very manifest sequences constituting a lunation, and those less manifest ones marking a year, and those still less manifest ones marking the planetary periods, astro-

[1] [Published in the *Essays*, Library Edition vol. ii. pp. 144–160.]

nomy occupied itself with such inconspicuous sequences as those displayed in the repeating cycle of lunar eclipses, and those which suggested the theory of epicycles and eccentrics; while modern astronomy deals with still more inconspicuous sequences, some of which, as the planetary rotations, are nevertheless the simplest which the heavens present." The solution of the problem of specific gravity by Archimedes, and the discovery of atmospheric pressure, nearly nineteen hundred years later, by Torricelli, involved mechanical relations of exactly the same kind; but the connection between antecedent and consequent was much more conspicuous in the former case than in the latter. The effect produced by the air in decomposing soil is a phenomenon just as simple as the rusting of iron or the burning of wood; but it is far less conspicuous, and accordingly chemistry generalized the one long before the other. Finally, if, remembering the enormous advance in science due to the telescope and microscope, and bearing in mind the equally astonishing results which are likely to arise from the use of the lately invented spectroscope, we ask what is the character of the service rendered us by these instruments, the reply is that they enable us to generalize phenomena which before were too inconspicuous to be generalized.

Again, other things equal, phenomena that are *frequent* have been scientifically explained sooner than unusual phenomena. "Rainbows and comets do not differ greatly in conspicuousness, and a rainbow is intrinsically the more involved phenomenon; but chiefly because of their far greater commonness, rainbows were perceived to have a direct dependence on sun and rain while yet comets were regarded as supernatural appearances."

In like manner the more *concrete* relations have been formulated before those that are more abstract. If we were to adhere rigorously to Comte's principle of decreasing generality, we should have to place the infinitesimal calculus before algebra, and algebra before arithmetic. But the order of development has been just the reverse, — from arithmetic, the least abstract department, to calculus, the most abstract.

Lastly I would suggest a circumstance, not mentioned by Mr. Spencer, namely that, other things equal, the sciences must advance according to the ratio between the complexity of the phenomena with which they deal and the multiplicity of our means for investigating those phenomena. I shall presently describe our three chief implements for extorting the secrets of Nature — observation, experiment, and comparison; showing that in general, as phenomena become more and more complicated, our ability to make use of these implements increases. In astronomy we have only observation to help us; but astronomic phenomena are comparatively simple, so that we have here a highly developed science. In biology we can use all three implements; and so, in spite of the complexity of vital phenomena, we have here a tolerably well-organized science. But in meteorology, we have to deal with very complex phenomena, and still have no resource save in steadfast observation. Hence meteorology is still a very backward science, — more backward even than sociology, of which the phenomena are far more complex.

According to Mr. Spencer, phenomena are also generalized early in proportion as they directly affect human welfare. But this circumstance would appear to have far less potency than the others above enumerated. There is, of course, no doubt that men will earliest study those subjects which most obviously concern them; but whether their study will be fruitful or not depends, as it seems to me, upon the other factors in the case above enumerated. I doubt if there is any instance in which this factor has actually overruled the other factors, as these have continually overruled each other. Sociology is the science which, more than all others, would seem to have direct practical bearings upon human welfare; yet, although men have studied social phenomena since the days of Plato, they have but lately arrived at any scientific generalizations concerning them. The daily changes of weather are more obviously concerned with human interests than the geological succession of extinct animals and vegetables; but our scientific knowledge of palæontology, though unsatisfactory enough, is yet far more advanced than our scientific knowledge of meteorology. No doubt men will soonest endeavour to understand the phenomena which most intimately concern them; but the order in which they will come to understand them will depend upon the simplicity, the concreteness, the conspicuousness, and the frequency of the phenomena, and upon the number and perfection of the implements of investigation which are at command. Indeed, from one point of view, it may be urged that direct complicity with human interests is often a hindrance to the scientific investigation of phenomena. Doubtless the disinterested calmness with which remote mathematical and physical inquiries are prosecuted is one secret of their success. As Hobbes remarked, with keen sarcasm, "even the axioms of geometry would be disputed if men's passions were concerned with them." And does not daily experience teach us the difficulty of getting our legislators to accept the simplest and most completely established principles of political economy?

Thus there are at least five separate factors determining the order and rate at which knowledge progresses; and it is the interaction of these factors which has made the actual order of scientific development too complex to be embraced in any linear formula, like that proposed by Comte. It is because it recognizes only one of these factors that the Comtean classification fails to represent the historic order in its true complexity. It makes a straight line where it ought to make a system of inosculating spirals.

Returning now from the historical to the logical point of view, we have to note a still more fundamental error in the Comtean classification. That classification rests primarily upon the distinction, above explained, between the abstract and the concrete sciences. That there is such a distinction cannot be questioned; but it will not be difficult to show that Comte has made the division incorrectly. When Comte contrasts chemistry with mineralogy, because the one formulates the abstract laws of the aggregation of heterogeneous molecules, while the other applies these laws to concrete instances actually realized in nature, under the influence of particular sets of conditions, the distinction must be admitted as valid. But when he similarly contrasts biology with zoölogy and botany, because the one formulates the general laws of life, while the others merely study the conditions of existence of particular genera and species, the distinction cannot be admitted as valid. In so far as zoölogy and botany are restricted to the mere description and enumeration of organic forms, they cannot strictly be called sciences at all, but only branches of natural history. In so far as they are anything more than this, they are a constituent part of biology. For, in biology, it is the study of the concrete conditions of existence of living organisms which lies at the bottom of the whole. The laws of nutrition, reproduction, and innervation are not abstract laws, considered apart from the conditions in which they are realized, like the law of inertia in physics, or the law of definite proportions in chemistry. They are realized in each concrete instance just as much as certain chemical and physical laws are realized in each concrete instance of mineralogy. Or — in other words — the laws of biology are derivative uniformities, while the laws of physics and chemistry are original uniformities. Given the general laws of molecular combination and decombination, and given also a certain definite organization placed in a given environment, and the laws of nutrition, reproduction, and innervation follow. Take away the definite organization, and you have nothing left but the laws of molecular rearrangement, which are the subjects of physics and chemistry. This is not identifying biology with physics and chemistry. The fact of organization remains, by the study of which biology is an independent science. But it is a concrete science, since it can study organization only as actually exemplified in particular organisms. The same is true of sociology, which is simply an extension of the principles of biology and psychology to the complex phenomena furnished by the mutual reactions of intelligent organisms upon each other. There is no abstract science of sociology which leaves out of sight the special complications arising from the interaction of concrete, actually existing communities. Any such abstract science is a mere figment of the imagination, born of Comte's excessive passion for systematizing. The science of sociology is the generalization of the concrete phenomena of society, as recorded in history; and, in the widest sense, the laws of sociology are the laws of history. And, travelling back to the other end of the series, a similar criticism must be made upon astronomy. This science is an application of molar physics (and latterly, in some degree, of molecular physics and chemistry) to the concrete phenomena presented by the heavenly bodies. The universal law of gravitation is indeed an abstract law; it formulates a property of bodies. But it holds good of terrestrial as well as of celestial phenomena: and its application to either class of phenomena, in their actual complications, constitutes a concrete science.

These are the considerations which irretrievably demolish the Comtean classification, considered as an expression of the true relations between the sciences. It appears that Comte has intermingled three abstract sciences — mathematics, physics, and chemistry — with three concrete sciences — astronomy, biology, and sociology. He was led into this confusion by confounding the *general* with the *abstract*. But, as Mr. Spencer has pointed out, these terms have different meanings. "Abstractness means *detachment from* the incidents of particular cases; generality means *manifestation in* numerous cases. On the one hand, the essential nature of some phenomenon is considered, apart from the phenomena which disguise it. On the other hand, the frequency of recurrence of the phenomenon, with or without various disguising phenomena, is the thing considered. An abstract truth is rarely if ever realized to perception in any one case of which it is asserted. A general truth may be realized to perception in all of the cases of which it is asserted. . . . In other words, a general truth colligates a number of particular truths; while an abstract truth colligates no particular truths, but formulates a truth which certain phenomena all involve, though it may be actually seen in none of them."[1]

Now there can be no question that if we were to substitute the words *general* and *special* for the words *abstract* and *concrete*, in the Comtean classification, that classification would express, to a certain extent, a true distinction. No doubt chemistry and biology are general sciences, while mineralogy, zoölogy, and botany are more or less special sciences. But the distinction between abstract and concrete is by far the deeper distinction, and because the Comtean classification incorrectly formulates it, there is no alternative but to regard that classification as incurably faulty.

The above criticism, however, supplies us with materials for making a better one. As the case now stands, we have three abstract sciences, — mathematics, physics, and chemistry. Yet a distinction in degree of abstractness arises between mathematics and the other two. All three were originally obtained by generalization from concrete phenomena. All mathematical analysis starts from numeration, as all geometry starts from measuring. Nevertheless mathematics has utterly outgrown the processes of concrete ob-

[1] Spencer, *Classification of the Sciences*, 1864, pp. 7–9.

servation, and is a purely deductive science, dealing merely with number and figure, or what may be called the blank forms of phenomena. It thus becomes more nearly allied to logic than to the physical sciences; and indeed the chief difference between the two is that logic deals with qualitative relations only, while mathematics deals with relations that are quantitative.[1] On the other hand, molar physics, molecular physics, and chemistry, dealing with abstract laws of motion and force that are gained from experience of concrete phenomena, and appealing at every step to the concrete processes of observation and experiment, may be distinguished as abstract-concrete sciences. These sciences analyze concrete phenomena, in order to formulate the working of their factors. "In every case it is the aim to decompose the phenomenon, and formulate its components apart from one another; or some two or three apart from the rest." The problem is to ascertain the laws of molar motion, or molecular vibration, or atomic rearrangement, not as these laws are actually realized to perception in any concrete example, "but as they would be displayed in the

1 [The prominence given in modern logical discussion to the non-quantitative portions of mathematical theory would probably have led Fiske to modify this statement. Certainly, there is mathematical science that does not deal with purely quantitative relations.]

absence of those minute interferences which cannot be altogether avoided." Conversely, when we come to the concrete sciences, — astronomy, geology, biology, psychology, and sociology, — our business is no longer analysis but synthesis. "Not to formulate the factors of phenomena is now the object; but to formulate the phenomena resulting from these factors under the various conditions which the Universe presents."

Thus we have distinguished three orders of sciences, — the abstract, the abstract-concrete, and the concrete. Our task is next to arrange the concrete sciences in some convenient and justifiable order. Mr. Spencer has constructed an elaborate tableau of these sciences, which is at once elegant and accurate, but which, for ordinary purposes, may profitably be abridged and condensed. Our principle of abridgment shall be a simple one. Since, in the concrete sciences, our object is to interpret the various orders of phenomena synthetically, as actually manifested throughout that portion of the universe which is accessible to our researches, — we cannot do better than arrange these sciences in the order in which their subject-phenomena have begun to be manifested in the course of universal Evolution.[1] First in order come the astronomical phe-

[1] See, in this connection, a very interesting letter by the distinguished geologist M. Cotta, in *La Philosophie Positive*, mai–juin, 1869; tom. iv. p. 486.

nomena presented by the genesis of the solar system from a cooling and contracting mass of vapour, and the resulting rotatory motions of its members. Next come the geological phenomena presented by each cooling and contracting planet, but completely accessible to us only in the case of the earth. With the origin of life upon the earth, already considerably advanced in its development, biological phenomena begin to be presented. Still later, with the appearance of animals possessing comparatively complex nervous systems, begin the phenomena of consciousness, constituting the subject-matter of psychology. Finally, with the advent of creatures sufficiently intelligent to congregate for mutual assistance in permanent family-groups, and by the aid of language to transmit their organized experience from generation to generation, there begin the phenomena of sociology.

The logical correctness of this threefold division of the sciences is shown by the fact that the several sciences which we have arranged together in each group cohere strongly among themselves, while they do not strongly cohere with the sciences arranged in either of the other groups. The concrete sciences, for example, all agree in having for their subject-matter the study of the *aggregates* of sensible existences, or of the relations and forces which sensible existences manifest in the state of aggregation. Sidereal Astronomy deals with stellar aggregates scattered through space just as we find them. "Planetary Astronomy, cutting out of this all-including aggregate that relatively minute part constituting the solar system, deals with this as a whole." Out of the number of aggregates which make up the whole with which planetary astronomy thus deals, Geology selects the one most easily accessible, and studies that one in detail. Again, among the many rearrangements of matter and motion which go on upon the earth's surface, there are found a number of small aggregates which Biology distinguishes as vital, and accordingly selects as constituting its own special subject-matter. Among the many functions which, taken together, make up the life of these organic aggregates, there are sundry "specialized aggregates of functions which adjust the actions of organisms to the complex activities surrounding them;" and these specialized aggregates of functions form the subject-matter of Psychology. Lastly, Sociology "considers each tribe and nation as an aggregate presenting multitudinous phenomena, simultaneous and successive, that are held together as parts of one combination." So that, from first to last, the object of the concrete sciences is to describe the history and formulate the modes of action of actually existing *aggregates*, from the time when they begin to exist as aggregates down to the time when they cease to exist as aggregates.

It is quite otherwise with the abstract-concrete sciences. By all these sciences, actually existing aggregates are implicitly ignored; "and a *property*, or a connected set of properties, exclusively occupies attention." It matters not to Molar Physics "whether the moving mass it considers is a planet or molecule, a dead stick thrown into the river or the living dog that leaps after it: in any case the curve described by the moving mass conforms to the same laws." So when Molecular Physics investigates "the relation between the changing bulk of matter and the changing quantity of molecular motion it contains," constant account is taken of connected sets of properties, but no account whatever is taken of particular aggregates of matter. The conclusions reached apply equally to Chimborazo and to a tea-kettle, to the solidification of the earth's crust and to the cracking of a pipe by frozen water. Similarly in Chemistry, while "ascertaining the affinities and atomic equivalence of carbon, the chemist has nothing to do with any aggregate. He deals with carbon in the abstract, as something considered apart from quantity, form, or appearance, or temporary state of combination; and conceives it as the possessor of powers or properties, whence the special phenomena he describes result, — the ascertaining of all these powers or properties being his sole aim." So that, from first to last, the object of the abstract-concrete sciences is to give an account "of some order of *properties*, general or special; not caring about the other traits of an aggregate displaying them, and not recognizing aggregates at all further than is implied by discussion of the particular order of properties."

Finally, the abstract sciences deal solely with *relations* among aggregates or among properties, or with the relations between aggregates and properties, or with relations among relations; but take no further account of aggregates or of properties than is implied in the discussion of a particular order of relations. For example, "the same Logical formula applies equally well, whether its terms are men and their deaths, crystals and their planes of cleavage, or letters and their sounds. And how entirely Mathematics concerns itself with relations, we see on remembering that it has just the same expression for the characters of an infinitesimal triangle as for those of the triangle which has Sirius for its apex and the diameter of the earth's orbit for its base."[1]

Since then, "these three groups of sciences are, respectively, accounts of *aggregates*, accounts of *properties*, accounts of *relations*, it is

[1] Spencer, *Recent Discussions*, pp. 107–110.

manifest that the divisions between them are not simply perfectly clear, but that the chasms between them are absolute." Thus we arrive at the following

CLASSIFICATION OF THE SCIENCES

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|---|---|---|
| ABSTRACT SCIENCES, dealing with *relations*, that are | qualitative; | Logic. |
| | quantitative; | Mathematics. |
| ABSTRACT-CONCRETE SCIENCES, dealing with *properties*, that are manifested | in movements of masses; | Molar Physics. |
| | in movements of molecules; *and* in aggregations of molecules that are homogeneous; | Molecular Physics. |
| | in aggregations of molecules that are heterogeneous; | Chemistry. |
| CONCRETE SCIENCES, dealing with *aggregates* (with their properties and relations), as actually exemplified | in stellar and planetary systems; | Astronomy. |
| | in the earth; | Geology. |
| | in living organisms; | Biology. |
| | in the functions which adjust organic actions to specific relations in the environment; | Psychology. |
| | in the mutual relations of living organisms grouped into communities; | Sociology. |

It remains to add that each of the five concrete sciences may, for the purposes of our philosophic synthesis, be advantageously regarded as consisting of two portions. In the first place, we have Astronomy — in the time-honoured sense of the word — which deals with the motions of stellar and planetary masses in their present state of moving equilibrium; and Astrogeny, as it is now frequently termed, which seeks to ascertain the genesis of these masses and of their motions.

Geology admits of a similar division. The general laws of the redistribution of gases and liquids over the earth's surface, which we commonly call meteorology, and the general laws of the formation of solid compounds, which we call mineralogy, unite to furnish us with a general doctrine of the massive and molecular motions going on at any given epoch and under any given geographic condition of the earth's surface. But geology has another clearly defined province, which is to formulate the general order of sequence among terrestrial epochs; to ascertain the genesis of the various molar and molecular redistributions going on at any given period, by regarding them as consequent upon the relations between a cooling rotating spheroid and a neighbouring sun which imparts to it thermal, luminous, and actinic undulations. This part of the science is already currently known as Geogeny. And here we touch upon the essential point of difference between geology and astronomy, regarded as sciences of development, which it seems to me that M. Wyrouboff, in his interesting essay upon this subject, has quite lost sight of. Both astrogeny and geogeny are concerned with the phenomena presented by a cooling and contracting body, of the figure known as a spheroid of rotation. In the one case this body is the sun, which once more than filled the orbit of Neptune; in the other case it is the earth, which at first more than filled the moon's orbit. But together with this point of community between the two sciences, there is a fundamental difference between them. While astrogeny contemplates the contracting spheroid chiefly as a generator of other spheroids, which are from time to time formed from its equatorial belt, detached as often as the centrifugal force at its equator begins to exceed the force of gravitation at the same place; on the other hand, geogeny contemplates the contracting spheroid only with reference to the redistributions of matter and motion going on within itself, and partly consequent upon its cooling. Partly consequent, I say, for there is one further point of difference between the two sciences. Astrogeny contemplates its spheroid as a radiator of heat, but neglects, as not affecting its own peculiar problems, the heat which the spheroid may receive by radiation from other masses. But geogeny not only studies its spheroid as a radiator of heat, but includes, as of the highest importance, the heat which it receives from an external source.

In Biology also the twofold point of view is obvious, according as we study structures and functions in mobile equilibrium at any particular epoch, or on the other hand the process of adaptation which structures and functions undergo as the conditions of existence change from epoch to epoch. The first of these studies gives rise to the sciences of anatomy and physiology, as well as to the subsidiary science of pathology. On the other hand Biogeny comprises embryology, morphology, and questions relating to the origin of species. Psychology too admits of a similar division, into the department which embraces the laws of association, as generalized by James Mill and further illustrated by Mr. Bain; and Psychogeny, which endeavours to interpret the genesis of intellectual faculties and emotional feelings in the race, and their slow modification throughout countless generations.

Finally in Sociology this principle of twofold division is so manifest that for the past thirty years the distinction has been currently, though too vaguely, drawn between "social statics" and "social dynamics." Obviously we may either study the phenomena arising from social aggregation, as they are manifested under any given set of conditions; or we may study the phenomena of progress manifested in the relations of each epoch to preceding and succeeding epochs. In the first case we have the sub-sciences of political economy, ethics, jurisprudence, etc.; in the second case we have Sociogeny, or the so-called "science of history."

In each of the five concrete sciences, therefore, there is a sub-science which deals with the genesis or evolution of the phenomena which form the subject-matter of the science; and it is with these sciences of genesis that we shall chiefly be concerned throughout the second part of this work. It is of little consequence, however, whether the symmetrical nomenclature here used be adopted or not. Excessive symmetry in naming is a mark of pedantry rather than of accuracy; and questions of terminology become important only when differences of opinion are involved. In reasoning about the Test of Truth, it makes a great difference whether we use the term "incredible" or the term "inconceivable." In the present discussion, it makes a great difference whether we speak of biology as an "abstract" or as a "concrete" science. But provided we bear in mind the twofold character of the problems which it is the office of biology to solve, it makes little difference whether or not we employ such a term as "biogeny;" and such expressions will be used, in the present work, only when it is desirable to avoid tedious circumlocution.

If now we proceed to inquire whether our revised classification can be made to afford us a bird's-eye view of the historic progression of the respective sciences, we shall find that it cannot be made to do so. The classification has been made upon purely logical grounds; and no attempt has been made to express the order of historic progression, simply because, as I have already shown, that order cannot be expressed by any linear series. If we were to represent the respective rates of progress in the different sciences by a device familiar to statisticians, — denoting the sciences by a series of curves, starting from the same point, and constructed with reference to a common abscissa; marking off the abscissa into equal sections and sub-sections answering to centuries and decades; and expressing the progress of each science at each decade by the length of the ordinate erected at the corresponding sub-section, — we should see these curves from first to last intersecting each other in the most complicated and apparently capricious manner. Probably the only conspicuously persistent relation would be that between the entire set of curves representing the concrete organic sciences, and all the rest of the curves taken together; of which two sets the former would, on the whole, have the shorter ordinates.

But on sufficiently close inspection we should detect, between the sets of curves representing the abstract, the abstract-concrete, and the concrete sciences, a relation equally constant, and far more interesting, though less conspicuous. We should observe that all along the progress of the concrete sciences has determined that of the abstract-concrete and abstract sciences, and has been determined by it — that, from first to last, synthesis and analysis have gone hand in hand. Such has been the complex order of progression. Men have begun by grouping concrete phenomena empirically. When the groups have become wide enough to allow the disclosure of some mode of force uniformly manifested in them, the operations of this force have begun to be experimentally or deductively studied, all disturbing conditions being as far as possible eliminated or left out of the account; and thus have arisen the analytic or abstract-concrete sciences. And finally, as fast as the laws of the various manifestations of force have been generalized, the synthetical interpretation of phenomena has advanced by the aid of the knowledge of these laws. As Mr. Spencer well expresses it: "there has all along been higher specialization, that there might be a larger generalization; and a deeper analysis, that there might be a better synthesis. Each larger generalization has lifted sundry specializations still higher; and each better synthesis has prepared the way for still deeper analysis." Long before Archimedes founded statics, the earliest branch of abstract-concrete science, empirical generalizations had been made in every one of the concrete sciences. Astronomy had accomplished the preliminary task of classifying stars according to their times of rising and setting, of tracing the apparent courses of the planets, of determining the order of recurrence of lunar eclipses, and of constructing chronological cycles. In geology some scanty progress had been made, in classifying the physical features of the earth's surface, and in ascertaining the properties of a limited number of minerals. In biology, classification had been carried sufficiently far to enable an acute observer, like Aristotle, to distinguish between the selachians, or shark-tribe, and the bony fishes; and a considerable amount of anatomical and physiological knowledge had been acquired, as may be seen in the works of Hippokrates. Even in psychology there had been made a crude classification of the intellectual and emotional functions; and the "Politics" of Aristotle show us the statical division of sociology already empirically organized. To such a point had the synthetic concrete sciences arrived in antiquity; and this point they did not pass until the analytic abstract-concrete sciences had furnished them with factors with which to work. Astronomy must still remain in the empirical stage until molar physics had generalized the abstract laws of falling bodies, of the composition of forces, and of tangential momentum. Geology could not advance until molecular physics had supplied the general principles of thermal radiation and conduction, of evaporation and precipitation, condensation and rarefaction. Biology was obliged to wait until chemistry had thrown light upon the molecular constitution of the various tissues and anatomical elements, and had furnished the means of explaining synthetically such organic processes as digestion and assimilation. But, as we have already seen, the obligation has not been all on one side. The services rendered by the analytic to the synthetic sciences have been all along repaid by services no less essential. Thus the great principle of molar physics — the law of gravitation — could not be generalized from terrestrial phenomena alone, but had to wait until astronomic observations had revealed the true forms of the planetary orbits and the rates of their velocities. Thus molecular physics has received important hints from mineralogy, the properties of crystals having rendered indispensable aid in the discoveries of polarization and double refraction, and therefore in the final verification of the undulatory theory. And thus also in late years the researches of Dumas, Laurent, Gerhardt, and Williamson on the structure of organic molecules have reacted upon the whole domain of inorganic chemistry, regenerating the doctrine of types, supplying the fundamental conceptions of atomicity and quantivalence, replacing the dualistic theory of Berzelius by the theory of saturation and substitution, and inaugurating a radical revolution in chemical nomenclature. I may note in passing that this great revolution, which has rendered the science of only half a generation ago completely antiquated, and has obliged so many of us to unlearn the chemistry which we learned at college, furnishes a crucial disproof of the Comtean theory of the way in which a scientific revolution should occur. We see that the chemistry of inorganic bodies was not placed upon its true foundation until the study of organic chemistry had supplied to the whole science its fundamental principles; in spite of Comte, who always scouted at organic chemistry as an illegitimate science, and predicted the speedy extension of the dualistic theory to organic compounds.

Space permitting, I might go on and point out more minutely how the allied sciences in each grand division have continually reacted upon each other; how synthesis has directly aided synthesis, and how analysis has directly aided analysis; how the analytic and the simpler synthetic sciences have from time to time furnished new hints to mathematics; and how all the other sciences, in all the divisions, from mathematics to sociology, have aided the progress of logic, supplying it with new methods of investigation and fresh canons of proof. But such a detailed survey is not needful for the purposes of this work. Let us rather return for a moment to our criticism of Comte; and having already examined his organization of the sciences both from the historical and from the logical point of view, let us endeavour to render an impartial verdict as to the philosophic value of his achievement.

If tried by its conformity to the ideal standard of perfection furnished by the scientific and philosophical knowledge of the present day, the Comtean classification of the sciences must undoubtedly be pronounced, in nearly all essential respects, a failure. As a representation of the historic order of progression among the different sciences, it must be regarded as the imperfect expression of an inadequately comprehended set of truths. We have seen that this order of progression depends upon at least five interacting factors: upon the simplicity, the concreteness, the conspicuousness, and the frequency of the phenomena investigated, and upon the comparative number and perfection of the implements of investigation. Of these five factors, the Comtean series takes into account only the first, or at the utmost only the first and the last. For this reason it unduly simplifies the order of progression. Doubtless it is correct to say that, other things equal, the simpler and more general phenomena have been interpreted earlier than the more complex and special phenomena; but the other things have not been equal. And consequently scientific evolution has not proceeded uniformly in a straight line, but rhythmically, in a plexus of curved lines.

As a representation of the logical order of subordination among the different sciences, the Comtean series is equally faulty. While it correctly formulates sundry of the minor relations of dependence, as well as one relation of great importance,—that of the dependence of organic upon inorganic science,—it incorrectly formulates the grand distinction of all,—the distinction between abstract and concrete, between analytic and synthetic science. It mixes together sciences formed by the analysis and synthesis of concrete phenomena, and a science which is purely abstract. It strives to represent, by a linear series, relations which are so complex that they can be adequately represented only in space of three dimensions.

It is therefore indisputable that the Comtean classification, viewed absolutely, is a failure. The advance of science has refuted instead of confirming it. It has become rather an encumbrance than a help to the understanding of the true relations among the sciences. Shall we then, with Professor Huxley, say that the classification, and with it the whole Comtean philosophy of science, is "absolutely worth-less?"[1] I think not. We might say as much of Oken or Hegel, but hardly of Stewart or Ampère — far less of Comte. Mr. Spencer speaks more justly of his great antagonist when he says, "Let it by no means be supposed from all I have said, that I do not regard M. Comte's speculations as of great value. True or untrue, his system as a whole has doubtless produced important and salutary revolutions of thought in many minds; and will doubtless do so in many more. Doubtless, too, not a few of those who dissent from his general views have been healthfully stimulated by the consideration of them. *The presentation of scientific knowledge and method as a whole, whether rightly or wrongly coördinated, cannot have failed greatly to widen the conceptions of most of his readers.* And he has done especial service by familiarizing men with the idea of a social science based on the other sciences. Beyond which benefits resulting from the general character and scope of his philosophy, I believe that there are scattered through his pages many large ideas that are valuable not only as stimuli, but for their actual truth."

This passage comes so near to appreciating Comte's true philosophic position, that one is surprised to find Mr. Spencer, after all, stating that position inadequately. Though he sees

[1] Huxley, *Lay Sermons*, p. 172.

clearly that, whether rightly or wrongly coördinated, the presentation of scientific knowledge and method *as a whole* must greatly have widened people's conceptions, he does not explicitly recognize that this presentation of scientific knowledge and method as a whole was, in spite of the wrong coördination, a step sufficient of itself to change and renovate the entire attitude of philosophy. He tells us that persons like Professor Huxley, Professor Tyndall, and himself stand substantially in the same position in which they would have stood had Comte never written; that, "declining his reorganization of scientific doctrine, they possess this scientific doctrine in its preëxisting state, as the common heritage bequeathed by the past to the present." And elsewhere he tells us that Comte "designated by the term 'Positive Philosophy' all that definitely established knowledge which men of science have been gradually organizing into a coherent body of doctrine." It seems to me, on the other hand, that the coherent body of doctrine was the very thing which no scientific thinker had ever so much as attempted to construct, though Bacon, no doubt, foresaw the necessity of some such construction. M. Littré may well inquire what is meant by the great scientific minds whose traditions Comte is said to have followed. "Does it mean the philosophers? Why, they have one and all belonged to theology or metaphysics, and it is not their tradition which Comte has followed. Does it mean those who have illustrated particular sciences? Well, since they have not philosophized, Comte can hardly have received his philosophy from them. That which is recent in the Positive Philosophy, that which is Comte's invention, is the conception and construction of a philosophy, by drawing from particular sciences, and from the teaching of great scientific minds, such groups of truths as could be coördinated on the positive method."

That the mode in which Comte effected this coördination was imperfect may affect our estimate of the amount of his achievements, but it cannot affect our estimate of their character. The former is a merely personal question, interesting chiefly to disciples; the latter is a general question, interesting to all of us who are students of philosophy. For the purposes of impartial criticism, the great point is, not that the attempt was a complete success, but that the attempt was made. When knowledge is advancing with such giant strides as at present, it is hardly possible to construct a general doctrine which forty years of further inquiry and criticism will not considerably modify and partially invalidate. It is now forty years since Comte framed his philosophy of science; and during that period there is not a single department of knowledge, outside of pure mathematics, which has not undergone a veritable revolution. Molecular physics has been revolutionized by the discovery of the correlation of forces; and the deduction of that principle, as well as of the principle of virtual velocities, from the law of the persistence of force, has placed molar physics also upon a new basis. Chemistry, as we have seen, has undergone changes nearly as sweeping as those brought about by Lavoisier; changes which have thoroughly renovated our conceptions of the phenomenal constitution of matter. Sidereal astronomy has been brought into existence as a science; and we have learned how to make a ray of light, journeying toward us from the remotest regions of space, tell us of the molecular constitution of the matter from which it started. Geology has been robbed of its cataclysms and periods of universal extinction; while both astrogeny and geogeny have assumed a new character through the wide extension of the theory of nebular genesis. There is not a truth in biology which has not been shown up in a new light by the victory of the cell-doctrine; the discovery of natural selection has entirely remodelled our conceptions of organic development; and the dynamical theory of stimulus has wrought great changes, which are but the beginning of greater changes, in pathology, in hygiene, and in the treatment of disease. Psychology, in both its branches, has received a scientific constitution by the establishment of the primary laws of association, and the fundamental law of the growth of intelligence. And sociology, both statical and dynamical, has undergone changes equally important, as we shall see when we come to treat specially of that subject. All this makes up an aggregate of scientific achievement such as the world has never before witnessed in anything like an equally short interval. So enormous is the accumulated effect of all these discoveries upon the general habits of thought, that the men of the present day who have fully kept pace with the scientific movement are separated from the men whose education ended in 1830 by an immeasurably wider gulf than has ever before divided one progressive generation of men from their predecessors. And when we add that both the history of science and the general principles upon which discoveries are made have been, during this interval and largely through the impulse given by Comte himself, more thoroughly studied than ever before, we may begin to realize how far the resources which we possess for constructing a synthesis of the sciences exceed the resources which were at his disposal. We shall realize that Comte — at least where physical science is concerned — has come to be almost an ancient; and we shall see that there may easily be injustice in criticising him as if he were a contemporary. We shall find the legitimate ground for wonder to be, not that he did so little, but that he did so much. And estimating him, as we estimate Bacon, from a purely historical point of view, we shall feel obliged to admit that the grand characteristic of the modern movement in philosophy — the continuous organization of scientific truths into a coherent body of doctrine — found in Comte its earliest, though by no means an adequate exponent. Previous to him, as M. Littré is right in reminding us, the field of general speculation belonged to metaphysics or theology, while science dealt only with specialities. It was owing to an impulse of which Comte is the earliest representative, that the tables were turned. The field of general speculation is now the property of science, while metaphysics and theology are presented as particular transitory phases of human thought.[1] Whatever, therefore, may be the case with Mr. Spencer — whose entire originality cannot for a moment be questioned — it is not true of the great body of scientific thinkers, that they stand in essentially the same position in which they would have stood had Comte never written. The course of speculative inquiry during the past forty years would no more have been what

[1] Littré, *Auguste Comte*, p. 99.

it is, without Comte, than the course of speculative inquiry during the past two centuries would have been what it is, without Bacon. And indeed, in Mr. Spencer's own case, — as he is himself disposed to admit, — there are several instances in which his very antagonism to Comte has led him to state certain important truths more clearly and more definitely than he would otherwise have been likely to state them. The theory of deanthropomorphization, set forth in the preceding chapter, was presented in a much more vivid light than would have been possible had it not been reached through an adverse criticism of the Comtean doctrine of the "Three Stages." The condemnation of Atheism involved in our statement of that theory is redoubled in emphasis when Positivism is by the same reasoning condemned; and our dissent from Hume is all the more strongly accented, when it is seen to be so complete as to include dissent from Comte also. So, too, the conclusions reached in the present chapter concerning the organization of the sciences are undeniably far more precise and satisfactory than they would have been if presented without reference to the earlier and necessarily cruder views of Comte. Indeed, in the very sense of incompleteness which would justly have attached itself to our exposition, had no mention been made of the Comtean theory, we may find fresh illustration of the fact that the errors of great minds are often no less instructive than the permanent truths which they have succeeded in detecting. And consequently, so far from decrying the Positive Philosophy or seeking to ignore it, we shall much better fulfil our duty as critics if we frankly acknowledge that the speculative progress of the nineteenth century would have been incomplete without it. Holding these views, and for these reasons, we may freely admit the justice of much that Professor Huxley urges against Comte: that his rejection of psychology was unphilosophical, and his acceptance of phrenology puerile; that his acquaintance with science was bookish and unpractical, and that his efforts to found a social polity were the very madness of utopian speculation. Had he committed twice as many such blunders, his general conception of philosophy and his contributions to the logic of science would have remained substantially unaffected in value. Had Bacon enrolled himself among the followers of Copernicus instead of adhering to the exploded theories of Ptolemaios, that fact would not by itself affect our estimate of the value of the "Novum Organon." And Comte's philosophic position, as I have here sought to define it, is no more shaken by his numerous scientific blunders than Bacon's position is shaken by the fact that he repudiated the

Copernican astronomy and refused to profit by the physical discoveries of Gilbert.

But the allusion to the Logic of Science may here serve to remind us that, before we can thoroughly understand Comte's general conception of philosophy, there is another point of view from which his system of the sciences must be criticised; a point of view too little dwelt upon by Mr. Spencer, since by the due consideration of it we shall arrive at the deepest of the differences between the Comtean organization of the sciences and the Spencerian organization which is here adopted. In order fairly to bring out this point, let us devote a chapter to considering the masterly enumeration of scientific methods, and the survey of the resources which the mind has at its disposal for the investigation of phenomena, which Comte has made a part of his general philosophy of the sciences; withholding, until the sequel, the application which is to be made of the discussion.

# CHAPTER IX

## PHILOSOPHY AS AN ORGANON

THE absence of Logic, as a distinct science, from the Comtean classification, has by most critics been rightly regarded as a serious defect. Nevertheless, before we can intelligently find fault with Comte, we must make sure that we understand his grounds for assigning to Logic no independent position. The explanation is more deeply implicated with his fundamental conception of the Scope of Philosophy than has generally been suspected. But let us begin by considering the more obvious aspects of the case.

The science of logic consists of two portions, — the doctrine of the syllogism, and the general theory of induction, the latter comprising a codification on the one hand of the methods of research, and on the other hand of the laws of evidence. But this twofold province of logic can hardly be said to have been clearly indicated until the publication of Mr. Mill's treatise. From the days of Aristotle down to the time when Comte wrote the "Philosophie Positive," the logic officially recognized and taught as such consisted almost exclusively of the doctrine of the syllogism. Besides this there was nothing save the Baconian logic, containing indeed many valuable hints for inquirers, but not organized into a coherent system. Now Comte held in small esteem the syllogistic logic. He held, and justly, that something besides the scholastic quibbling over *Baroco*, *Camestres*, and *Barbara*, was needed in prosecuting the search after new truths. To attempt, by prolonged dealing in these dialectic subtleties, to acquire the art of correct reasoning, was, in his opinion, much like trying to learn the art of correct speaking by prolonged study of the rules of grammar. Men do not learn to swim, to fence, or to hunt, by reading elaborate treatises on gymnastics and sportsmanship. The study of rhetoric, however thorough, careful, and systematic, will never of itself enable us to write a clear and forcible style. We may know all the commandments of ethics by heart, and be able to utter the soundest judgment upon the comparative merits of the utilitarian and the intuitional theories, and yet be unable to lead upright lives. And similarly we may go on stringing together majors and minors until we are gray, and yet after all be unable to make an accurate observation, or perform a legitimate induction. Therefore, according to Comte, logic is not so much a science as an art, indispensable in the prosecution of all the sciences, but to be learned only by practice. As philosophy, regarded as a general conception of the universe, has hitherto like the mistletoe had its roots in the air, but has now been brought down and securely planted in the fertile soil of scientific knowledge, so let us no longer permit logic to remain in isolation, feeding upon airy nothings, but let us bring it down and nourish it with scientific methods. As we learn to live rightly, not by dogmatic instruction, but by the assiduous practice of right living, as we learn to speak properly and to write forcibly by practice and not by theory, so let us gain control of the various instruments for investigating Nature by the study of the several sciences in which those instruments come into play. To become skilful in the use of deduction, let us study mathematics, especially in its direct applications to the solution of problems in astronomy and physics. If we would become accurate observers, and would enable ourselves properly to estimate the value of experimental reasoning, let us study those inductive sciences which exhibit practically the essential requisites of an accurate observation or a conclusive experiment. Even so, if we would attain literary excellence, let us not fritter away our time in puerile attempts to imitate the favourite modes of expression of admired writers, but let us rather aim at directly expressing the thoughts that are in us, the result of our own observation and reflection, admitting no phrase which does not assist the exposition of the thought. If, as Buffon said, the style is the man, so also is the habit of thinking the man, save that in the one case as in the other, if it possess any merit, it is the man as modified and cultivated by a complex intercourse with phenomena.

Such is Comte's opinion of logic, — an opinion common enough at the present day, but sufficiently novel to be revolutionary forty years ago. That the above views are in the main perfectly sound will now be questioned by no one, nor can it be doubted that they are of the highest importance. When put into practical operation, they are destined to work changes of fundamental importance in our methods of education. Nevertheless, though sound enough as far as they go, these arguments are far from exhibiting the whole truth. Admitting unreservedly that, to become proficient in observation and reasoning, we must learn logic, as we learn grammar and rhetoric, by practical experience, it must still be maintained that there is need of a general doctrine of logic, as indeed there is also need of a general doctrine of grammar and rhetoric. Though a man may write an excellent style without having studied rhetoric systematically, yet it will be no injury, but rather an important help to him to understand theoretically the general principles on which a sentence should be constructed. In the fine arts, which afford an excellent test for judging this point, the superiority imparted by systematic instruction is quite incontestable. Doubtless it is by long-continued practice that men learn to paint pictures, to mould statues, and to compose oratorios or symphonies. But it is none the less probable that Mozart and Beethoven would have accomplished comparatively little without the profound study of harmony; and in painting and sculpture the "originality of untaught geniuses" is, not unjustly, made a subject for sarcasm. It is therefore useless for Macaulay to remind us that men reasoned correctly long before Bacon had drawn up his elaborate canons of induction; or for Comte to appeal to rhetoric, grammar, and æsthetic art in support of the opinion that we need no general doctrine of logic.

To take a concrete example, — if, as in Borda's experiment, you make a simple pendulum oscillate thirty hours in an exhausted receiver, by diminishing the friction at the point of support, and proceed to infer that with the total abolition of friction and atmospheric resistance the pendulum would oscillate forever, it may not be essential to the validity of your inference that you should understand the character of the particular logical method which you are employing. Nevertheless it cannot but be of advantage to you to know that you are using the "method of concomitant variations," and to understand on general principles the conditions under which this method may be employed and the precautions required in order to make it valid. For want of such general knowledge of method, even trained physicists not unfrequently make grave errors of inference, applying some powerful implement of research in cases where interfering circumstances, not sufficiently taken into account, render it powerless. Thus the method just alluded to, of varying the cause in order to observe and note the concomitant variations of the effect, is a very powerful instrument of induction; but in order to use it effectively, we need to bear in mind two things. First, we need to know the quantitative relation between the variation of the cause and that of the effect; and secondly, we need to know that the intermixture of circumstances will not, after a certain point, alter the order of the variations. In the case of the pendulum, just cited, we know both of these points. We know that the only factors in the case are the momentum of the pendulum, acting in concert with gravity, the friction at the point of support, and the friction and resistance of the atmosphere; and as we progressively diminish these latter retarding factors, we can calculate the exact ratio at which the retardation diminishes. We are therefore perfectly justified in concluding that if the friction and resistance could be utterly abolished, the momentum of the pendulum, acting in concert with gravity, would carry it backward and forward forever. But because the abstraction of heat causes the molecules of a body to approach each other, it is not safe to infer that, if all the heat were abstracted, the molecules would be in complete contact. This is a more or less plausible guess, not a true induction. "For since we neither know how much heat there is in any body, nor what is the real distance between any two of its particles, we cannot judge whether the contraction of the distance does or does not follow the diminution of the quantity of heat according to such a numerical relation that the two quantities would vanish simultaneously."[1] In similar wise, from the fact that in alcoholic intoxication the severity of the narcotic symptoms varies according to the size of the dose, it is not legitimate to infer that a very small dose will cause slight narcotic symptoms or even a tendency to the production of such symptoms. For we can neither ascertain the quantitative ratio between the variation in the dose and the variation in the narcosis, nor in the case of such a complex

[1] Mill, *System of Logic*, 6th edition, vol. i. p. 447.

aggregate as the human organism can we assert the absence of interfering conditions which, after a certain point, will entirely change the order of the two variations. In point of fact there are such interfering conditions, due partly to the control exercised by the sympathetic nerve over the contraction and dilatation of the cerebral blood-vessels, and partly to other circumstances too complicated to be here mentioned.

Now it is the business of logic to codify, upon abstract principles, the rules of scientific investigation; to determine what shall be admitted as trustworthy evidence, and what shall not be so admitted; to point out the class of problems which each implement of research is best fitted to solve; and to enumerate the precautions which must be taken in order to use each implement with skill and success. Logic is therefore a science which contributes to all the others, and to which all the others contribute. Though we may, and indeed must, acquire familiarity with its methods by direct practice in the study of the various sciences, yet the advantage of understanding the general theory of those methods, as a science by itself, cannot well be questioned after the foregoing explanation. To become familiar with the values of different kinds of evidence, and with the processes by which evidence is procured, a lawyer must practise in court; yet every lawyer thinks it necessary to master the general theory of evidence as presented in special treatises. Logic is to the philosopher and the scientific inquirer what the law of evidence is to the lawyer; and the need for its theoretical study rests upon the admitted principle that, in all branches of human activity, rational knowledge is better than empirical knowledge. In order to be always sure that we are generalizing correctly, we must make the generalizing process itself a subject of generalization.

But although Comte did not dignify logic with the rank of an independent science, he more than atoned for the omission by his contributions to the study of logic. Since the era of Bacon and Descartes, no book had appeared containing such profound views of scientific method as the "Philosophie Positive." It has since been surpassed and superseded in many respects by Mr. Mill's "System of Logic;" but Mr. Mill would be the first to admit that, but for the work of Comte, his own work would have been by no means what it is.[1]

Comte's most important innovation consisted in comprehensively assigning to each class of phenomena its appropriate method of investigation, and in clearly marking out the limits within which each method is applicable. It is

[1] This is perhaps too strongly stated. See Mill's *Autobiography*, pp. 207–213, 245.

this which gives to the first three volumes of the "Philosophie Positive" the character of a general treatise on scientific method, and which makes them still interesting and profitable reading, even in those chapters on physics, chemistry, and biology, which in nearly all other respects the recent revolutions in science have rendered thoroughly antiquated. Comte intended this portion of his work especially for a new Organon of scientific research, which should influence educational methods in the future, as well as assist in determining the general conception of the universe. He calls attention to the futility of approaching the most complicated phenomena, such as those of life, individual or social, without having previously, by the study of the simpler sciences, learned what a law of nature is, what a scientific conception is, what is involved in making an accurate observation, what is requisite to a sound generalization, what are the various means of verifying conclusions obtained by deduction. Continually we witness the spectacle of scientific specialists, justly eminent in their own department of research, who do not scruple to utter the most childish nonsense upon topics with which they are but slightly acquainted. The reason is that they have learned to think correctly after some particular fashion, but know too little of the general principles on which thinking should be conducted. In such a condition — owing to the discredit which the manifest failure of metaphysics has for the time being cast upon philosophy in general — are too many of our scientific savants of the present century; whose narrowness of mind, in dealing with philosophic questions, Comte was never weary of pointing out and tracing to its true source in the defective mastery of logical methods. The cure for this narrowness is to be found in a philosophic education which shall ensure familiarity with all logical methods by studying each in connection with that order of phenomena with which it is most especially fitted to deal.

According to Comte, the resources which the mind has at its disposal for the inductive investigation of phenomena are three in number, — namely, Observation, Experiment, and Comparison. Strictly speaking, experiment and comparison are only more elaborate modes of observation; but they are nevertheless sufficiently distinct from simple observation to make it desirable, for practical purposes, to rank them as separate processes. Concisely stated, the difference is as follows: In simple observation, we merely collate the phenomena, as they are presented to us. In experiment, we follow the Baconian rule of artificially varying the circumstances. In comparison, we watch the circumstances as they are varied for us on a great scale by Nature.

Answering to the two processes of observation and experiment, as Mr. Mill has shown, there are two inductive methods, — the Method of Agreement and the Method of Difference. The former compares different instances of a phenomenon, to ascertain in what respects they agree, while the latter compares an instance of the occurrence of a phenomenon with an instance of its non-occurrence, to ascertain in what respects they differ. To cite from Mr. Mill's "System of Logic" a pair of examples, — "When a man is shot through the heart, it is by the method of difference we know that it was the gun-shot which killed him; for he was in the fulness of life immediately before, all circumstances being the same except the wound." On the other hand, in inquiring into the cause of crystallization, we employ the method of agreement as follows: "We compare instances in which bodies are known to assume crystalline structure, but which have no other point of agreement; and we find them to have one, and as far as we can observe, only one, antecedent in common, — the deposition of a solid matter from a liquid state, either a state of fusion or of solution. We conclude, therefore, that the solidification of a substance from a liquid state is an invariable antecedent of its crystallization." In this particular case we may say that it is not only the invariable antecedent, but the unconditional invariable antecedent, or cause; since, having detected the antecedent, we may produce it artificially, and find that the effect follows it. It was thus in Sir James Hall's splendid experiment, in which "he produced artificial marble by the cooling of its materials from fusion under immense pressure." And it was thus when Dr. Wollaston, "by keeping a vial of water charged with silicious particles undisturbed for years, succeeded in obtaining crystals of quartz."

Manifestly, however, unless we can artificially produce the antecedent, and so reason back from cause to effect, our method of agreement is not exhaustively conclusive. Unless we can be sure that the observed antecedent is the only one common to all the instances, the sequence may turn out to be only a derivative sequence, like that of day and night. And unless the phenomena are very simple, we cannot be sure that the oberved common antecedent is the only one. It is otherwise with the method of difference. Whenever we can bring that method to bear upon the phenomena, its results are finally conclusive; since it is the very essence of that method to compare two instances which are exactly alike in every respect save in the presence or absence of the given antecedent. Unfortunately in the operations of nature these requisites are seldom fulfilled: so that the method of difference "is more particularly a method of artificial experiment; while that of agreement is more especially the resource employed where experimentation is impossible."

Now in astronomy we can employ only simple observation. The magnitude and the inaccessibility of the phenomena render it impossible for us to vary the circumstances, so that experiment is out of the question. Nevertheless here the phenomena are so simple that the method of agreement alone carries us far toward certainty; and accordingly in astronomy the art of observation has been brought to such a pitch of perfection, and the conditions of an accurate observation are so thoroughly understood, that it is here that the use of this implement of induction must be studied.

In physics, both molar and molecular, and in chemistry, the phenomena become far more complicated. Yet here we become able to vary the phenomena almost indefinitely; and accordingly physics and chemistry are the inductive sciences *par excellence*, in which experiment, the great engine of induction, is employed most successfully, and in which, therefore, is especially to be studied the proper use of the method of difference.

When we come to biology, we are met by a still greater complication of phenomena; but according to the luminous principle, first suggested by Comte, that in general our means of investigation increase with the complexity of the phenomena, we have here an additional weapon of investigation. We still retain the ability to experiment; although such is the intricacy of the circumstances, and such the subtlety of the causes in operation, that we can seldom apply the potent method of difference. We can seldom be sure that the two instances compared agree in everything save in the presence or absence of the circumstance we are studying.[1] In experimenting upon live animals, we are liable to cause a pathological state, and set in motion a whole series of phenomena which obscure those which we wish to observe. It is instructive, and often amusing, to read some treatise on experimental physiology, like those of Magendie and Claude Bernard, and see how easy it is for equally careful investigators to arrive at totally irreconcilable results. It is not to be denied that experiment is of vast importance in biology, and has already achieved wonders. Nevertheless the practical study of experimentation should never be begun in biology, but

[1] A striking illustration of this truth is furnished by the controversy now going on concerning archebiosis, or "spontaneous generation." See below, Part II. chap. viii.

in chemistry or physics, where the conditions are simpler. Having learned from these sciences the general theory of sound experimenting, we may afterward safely proceed to apply the same method to vital phenomena.

The additional implement possessed by the organic sciences is comparison, to which corresponds the Method of Concomitant Variations, already described. It is true we can also employ this method to a large extent in the simpler sciences, but it is in biology that it attains its maximum efficiency. Here we have a series of instances already prepared for us by Nature, in which certain antecedents and consequents vary together. We have a vast hierarchy of organisms, each exhibiting some organ and the corresponding function more or less developed than it is in the others. To trace the functions of the nervous system, or to follow the process of digestion, in its increasing complication, from the star-fish up to man, is to employ the logical method of comparison. And if any one wishes to realize the immense power of this method, let him reflect upon the revolution which was wrought in the science of biology when Lamarck and Cuvier began the work of comparison upon a large scale.

Hence it is that biology is eminently the science of classification; and if skill in the use of this powerful auxiliary of thought is to be acquired, it must be sought in the comparative study of the vegetable and animal kingdoms. Theoretical logic may divide and subdivide as much as it likes; but genera and species are dull and lifeless things, when contemplated merely in their places upon a logical chart. To become correct reasoners, it is not enough that we should know what classes and sub-classes are; we should also be able skilfully to make them. I conclude with a citation from Mr. Mill: "Although the scientific arrangements of organic nature afford as yet the only complete example of the true principles of rational classification, whether as to the formation of groups or of series, those principles are applicable to all cases in which mankind are called upon to bring the various parts of any extensive subject into mental coördination. They are as much to the point when objects are to be classed for purposes of art or business, as for those of science. The proper arrangement, for example, of a code of laws depends on the same scientific conditions as the classifications in natural history; nor could there be a better preparatory discipline for that important function than the study of the principles of a natural arrangement, not only in the abstract, but in their actual application to the class of phenomena for which they were first elaborated, and which are still the best school for learning their use. Of this, the great authority on codification, Bentham, was perfectly aware; and his early 'Fragment on Government,' the admirable introduction to a series of writings unequalled in their department, contains clear and just views (as far as they go) on the meaning of a natural arrangement, such as could scarcely have occurred to any one who lived anterior to the age of Linnæus and Bernard de Jussieu."[1]

These illustrations will serve to give the reader some idea of Comte's brilliant and happy contributions to the logic of scientific inquiry. I am aware that scanty justice is done to the subject by the condensed and abridged mode of treatment to which I have felt obliged to resort. But an exhaustive exposition and criticism of the details of the Comtean philosophy of method does not come within the scope of the present work. The object of the preceding sketch is to enable the reader to realize the significance of Comte's omission of Logic from the scheme of the sciences. *That omission*, as we may now see, *was due to the fact that Comte merged Philosophy in Logic*. Or, in other words, *from his point of view*, *Philosophy is not a Synthesis*, *but an Organon*. Nowhere in that portion of the "Philosophie Positive" which treats of the organization of the sciences, do we catch any glimpse of that Cosmic conception of the scope of phi-

[1] *System of Logic*, 6th edition, vol. ii. p. 288.

losophy which was set forth and illustrated in the second chapter of these Prolegomena. For according to that conception, we have seen that philosophy is an all-comprehensive Synthesis of the doctrines and methods of science; a coherent body of theorems concerning the Cosmos, and concerning Man in his relations to the Cosmos of which he is part. Now, though Comte enriched mankind with a new conception of the aim, the methods, and the spirit of philosophy, he never even attempted to construct any such coherent body of theorems. He constructed a classification of the sciences and a general theory of scientific methods; but he did not extract from each science that quota of general doctrines which it might be made to contribute toward a universal doctrine, and then proceed to fuse these general doctrines into such a universal doctrine. From first to last, so far as the integration of science is concerned, his work was logical rather than philosophical. And here we shall do well to note an apparent confusion between these two points of view, which occurs in Mr. Mill's essay on Comte. "The philosophy of science," says Mr. Mill, "consists of two principal parts: the methods of investigation, and the requisites of proof. The one points out the roads by which the human intellect arrives at conclusions; the other, the mode of testing their evidence. The former, if complete, would be an Organon of Discovery; the latter, of Proof." Now I call this an admirable definition; but it is not the definition of Philosophy, it is the definition of Logic. If we were to accept it as a definition of philosophy, we might admit that Comte constructed a philosophy; as it is, we can only admit that he constructed a logic, or general theory of methods. In the present chapter we have seen how valuable were his contributions to the logic of induction. We may admit, with Mr. Mill, that he treats this subject "with a degree of perfection hitherto unrivalled," — save (I should say) by Mr. Mill himself. But an Organon of Methods is one thing, and a Synthesis of Doctrines is another thing; and a system of philosophy which is to be regarded as a comprehensive theory of the universe must include both. Yet Comte never attempted any other synthesis than that wretched travesty which, with reference to the method employed in it, is aptly entitled "Synthèse Subjective."

Not only does Comte thus practically ignore the conception of philosophy as a Synthesis of the most general truths of science into a body of universal truths relating to the Cosmos as a whole, but there is reason to believe that had such a conception been distinctly brought before his mind, he would have explicitly condemned it as chimerical. In illustration of this

I shall, at the risk of apparent digression, cite one of his conspicuous shortcomings which is peculiarly interesting, not only as throwing light upon his intellectual habits, but also as exemplifying the radical erroneousness of his views concerning the limits of philosophic inquiry. Professor Huxley calls attention to Comte's scornful repudiation of what is known as the "cell-doctrine" in anatomy and physiology. Comte characterized this doctrine as a melancholy instance of the abuse of microscopic investigation, a chimerical attempt to refer all tissues to a single primordial tissue, "formed by the unintelligible assemblage of a sort of organic monads, which are supposed to be the ultimate units of every living body." Now this "chimerical doctrine" is at the present day one of the fundamental doctrines of biology. Other instances are at hand, which Professor Huxley has not cited. For example, Comte condemned as vain and useless all inquiries into the origin of the human race, although, with an inconsistency not unusual with him, he was a warm advocate of that nebular hypothesis which seeks to account for the origin of the solar system. As these two orders of inquiry are philosophically precisely on a level with each other, the former being indeed the one for which we have now the more abundant material, the attempted distinction is proof of the vagueness with which Comte conceived the limits of philosophic inquiry.[1] But what shall we say when we find him asserting the impossibility of a science of stellar astronomy? He tells us that we have not even the

[1] It is interesting to note that disciples of Comte are still to be found, so incapable of realizing that the arbitrary dicta of their master did not constitute the final utterance of human science, that they oppose the Doctrine of Evolution upon no other ground than the assumed incapacity of the human mind for dealing with origins! In a discussion held in New York some two years since on the subject of "Darwinism," a certain disciple of Comte observed that it was useless for man to pretend to know how he originated, when he could not ascertain the origin of anything! Nevertheless, since we do find ourselves able to point out the origin of many things, from a myth or a social observance to a freshet or the fall of an avalanche, it appears that our Comtist was playing upon words after the scholastic or Platonic fashion, and confounding proximate "origin," which is a subject for science, with ultimate "origin," which must be relegated to metaphysics. Had Comte carried out this principle consistently, he would never have written his Philosophy of History, since the explanation of the social phenomena existing in any age is the determination of their mode of origin from the social phenomena of the preceding age. But if with the aid of historic data we may go back three thousand years, there is no reason why, with the aid of geologic, astronomic, and chemical data, we should not go back, if necessary, a thousand billion years, and investigate the origin of the earth from the solar nebula, or the origin of life from aggregations of colloidal matter. In either case, the problem is one, not of ultimate origin, but of evolution. In neither case do we seek to account for the origin of the matter and motion which constitute the phenomenal universe, but only to discover a formula which shall express the common

first datum for such a science, and in all probability shall never obtain that datum. Until we have ascertained the distance, and calculated the proper motion, of at least one or two fixed stars, we cannot be certain even that the law of gravitation holds in these distant regions. And the distance of a star we shall probably never be able even approximately to estimate. Thus wrote Comte in 1835. But events, with almost malicious rapidity, falsified his words. In less than four years, Bessel had measured the parallax of the star 61 Cygni, — the first of a brilliant series of discoveries which by this time have made the starry heavens comparatively familiar ground to us. What would Comte's scorn have been, had it been suggested to him that within a third of a century we should possess many of the data for a science of stellar chemistry; that we should be able to say, for instance, that Aldebaran contains sodium, magnesium, calcium, iron, bismuth, and antimony, or that all the stars hitherto observed with the spectroscope contain hydrogen, save *β* Pegasi and *a* Orionis, which apparently do not! Or what would he have said, had it been told him that, by the aid of the same instrument which

characteristics of certain observed or inferred redistributions of the matter and motion already existing. The latter attempt is as clearly within the limits of a scientific philosophy as the former is clearly beyond them.

now enables us to make with perfect confidence these audacious assertions, we should be able to determine the proper motions of stars which present no parallax! No example could more forcibly illustrate the rashness of prophetically setting limits to the possible future advance of science. Here are truths which, within the memory of young men, seemed wholly out of the reach of observation, but which are already familiar, and will soon become an old story.

I believe it was Comte's neglect of psychological analysis which caused him to be thus over-conservative in accepting new discoveries, and over-confident in setting limits to scientific achievement. He did not clearly distinguish between the rashness of metaphysics and the well-founded boldness of science. He was deeply impressed with the futility of wasting time and mental energy in constructing unverifiable hypotheses; but he did not sufficiently distinguish between hypotheses which are temporarily unverifiable from present lack of the means of observation, and those which are permanently unverifiable from the very nature of the knowing process. There is no ground for supposing that Comte ever thoroughly understood *why* we cannot know the Absolute and the Infinite. He knew, as a matter of historical fact, that all attempts to obtain such knowledge had miserably failed, or ended in nothing better than vain verbal wranglings; but his ignorance of psychology was so great that he probably never knew, or cared to know, why it must necessarily be so. Had he ever once arrived at the knowledge that the process of knowing involves the cognition of likeness, difference, and relation, and that the Absolute, as presenting none of these elements, is trebly unknowable, he would never have confounded purely metaphysical hypotheses with those which are only premature but are nevertheless scientific. He would have seen, for instance, that our inability to say positively whether there are or are not living beings on Saturn results merely from our lack of sufficient data for a complete induction; whereas our inability to frame a tenable hypothesis concerning matter *per se* results from the eternal fact that we can know nothing save under the conditions prescribed by our mental structure. Could we contrive a telescope powerful enough to detect life, or the products of art, upon a distant planet, there is nothing in the constitution of our minds to prevent our appropriating such knowledge; but no patience of observation or cunning of experiment can ever enable us to know the merest pebble as it exists out of relation to our consciousness. Simple and obvious as this distinction appears, there is much reason to believe that Comte never understood it. He inveighs against inquiries into the proximate origin of organic life in exactly the same terms in which he condemns inquiries into the ultimate origin of the universe. He could not have done this had he perceived that the latter question is forever insoluble because it involves absolute beginning; whereas the former is merely a question of a particular combination of molecules, which we cannot solve at present only because we have not yet obtained the requisite knowledge of the interactions of molecular forces, and of the past physical condition of the earth's surface. In short, he would have seen that, while the human mind is utterly impotent in the presence of noumena, it is well-nigh omnipotent in the presence of phenomena. In science we may be said to advance by geometrical progression. Here, in the forty years which have elapsed since Comte wrote on physical science, it is hardly extravagant to say that the progress has been as great as during the seventeen hundred years between Hipparchos and Galileo. If then, in the three or four thousand years which have elapsed since Europe began to emerge from utter barbarism, we have reached a point at which we can begin to describe the chemical constitution of a heavenly body seventy thousand million miles distant, what may not science be destined to achieve in the next four thousand or forty thousand years? We may rest assured that the tale, if we could only read it, would far excel in strangeness anything in the "Arabian Nights" or in the mystic pages of the Bollandists.

But Comte did not understand all this. He, the great overthrower and superseder of metaphysics, did not really apprehend the distinction between metaphysics and science. Hence every hypothesis which went a little way beyond the limited science of his day he wrongly stigmatized as "metaphysical." Hence he heaped contumely upon the cell-doctrine, only three years before Schwann and Schleiden finally established it. And hence, when he had occasion to observe that certain facts were not yet known, he generally added, "and probably they never will be," — though his prophecy was not seldom confuted, while yet warm from the press.

Toward the close of his life, after he had become sacerdotally inclined, this tendency assumed a moral aspect. These remote and audacious inquiries into the movements of stars, and the development of cellular tissue, and the origin of species should not only be pronounced fruitless, but should be frowned upon and discountenanced by public opinion, as a pernicious waste of time and energy, which might better be devoted to nearer and more practical objects. It is a curious illustration of the effects of discipleship upon the mind, that several of Comte's disciples — Dr. Bridges among others less distinguished — maintain this same opinion, for no earthly reason, I imagine, save that Comte held it. It is certainly a strange opinion for a philosopher to hold. It bears an unlovely resemblance to the prejudice of the Philistines, that all speculation is foolish and empty which does not speedily end in bread-and-butter knowledge. Who can decide what is useful and what is useless? We are told first that we shall never know the distance to a star, and secondly that even if we could know it, the knowledge would be useless, since human interests are at the uttermost bounded by the solar system. Three years suffice to disprove the first part of the prediction. In a little while the second part may also be disproved. We are told by Comte that it makes no difference to us whether organic species are fixed or variable; and yet, as the Darwinian controversy has shown, the decision of this question must affect from beginning to end our general conception of physiology, of psychology, and of history, as well as our estimate of theology. If it were not universally felt to be of practical consequence, it would be argued calmly, and not with the weapons of ridicule and the *odium theologicum*. But this position — the least defensible one which Comte ever occupied — may best be refuted by his own words, written in a healthier frame of mind. "The most important practical results continually flow from theories formed purely with scientific intent, and which have sometimes been pursued for ages without any practical result. A remarkable example is furnished by the beautiful researches of the Greek geometers upon conic sections, which, after a long series of generations, have renovated the science of astronomy, and thus brought the art of navigation to a pitch of perfection which it could never have reached but for the purely theoretic inquiries of Archimedes and Apollonios. As Condorcet well observes, the sailor, whom an exact calculation of longitude preserves from shipwreck, owes his life to a theory conceived two thousand years ago by men of genius who were thinking of nothing but lines and angles." This is the true view; and we need not fear that the scientific world will ever adopt any other. That inborn curiosity which, according to the Hebrew legend, has already made us like gods, knowing good and evil, will continue to inspire us until the last secret of Nature is laid bare; and doubtless, in the untiring search, we shall uncover many priceless jewels, in places where we least expected to find them.

The foregoing examples will suffice to illustrate the vagueness with which Comte conceived the limits of scientific and of philosophic inquiry. I have here cited them, not so much for the sake of exhibiting Comte's mental idiosyncrasies, as for the sake of emphasizing the radical difference between his conception of the scope of philosophy and the conception upon which the Cosmic Philosophy is founded. In giving to Comte the credit which he deserves, for having heralded a new era of speculation in which philosophy should be built up entirely out of scientific materials, we must not forget that his conception of the kind of philosophy thus to be built up was utterly and hopelessly erroneous. Though he insisted upon the all-important truth that philosophy is simply a higher organization of scientific doctrines and methods, he fell into the error of regarding philosophy merely as a logical Organon of the sciences, and he never framed the conception of philosophy as a Universal Science in which the widest truths obtainable by the several sciences are contemplated together as corollaries of a single ultimate truth. Not only did he never frame such a conception, but there can be no doubt that, had it ever been presented to him in all its completeness, he would have heaped opprobrium upon it as a metaphysical conception utterly foreign to the spirit of Positive Philosophy. We have just seen him resolutely setting his face against those very scientific speculations to which this conception of the scope of philosophy owes its origin; and we need find no difficulty in believing Dr. Bridges when he says that the Doctrine of Evolution would have appeared to his master quite as chimerical as the theories by which Thales and other Greek cosmogonists "sought to deduce all things from the principle of Water or of Fire."

Thus in a way that one would hardly have anticipated, we have disclosed a fundamental and pervading difference between the Positive and the Cosmic conceptions of philosophy. The apparently subordinate inquiry into Comte's reasons for excluding Logic from his scheme of sciences, has elicited an answer which gravely affects our estimate of his whole system of thought. That his conception of Philosophy as an Organon was a noble conception, there is no doubt; but that it was radically different from our conception of Philosophy as a Synthesis, is equally undeniable. But the full depth and significance of this distinction will only be appreciated when, in the following chapter, we shall have pointed out the end or purpose for which this scientific Organon was devised.

# CHAPTER X

## COSMISM AND POSITIVISM

TOWARD the close of the chapter on "Phenomenon and Noumenon," I observed that it has become customary to identify with Positivism every philosophy which rejects all ontological speculation, which seeks its basis in the doctrines and methods of science, and which is accordingly arranged in opposition to the current mythologies. The confusion is one which, after having once been originated, it is easy to maintain but exceedingly difficult to do away with; since on the one hand, it is manifestly convenient for the theologian to fasten upon every new and obnoxious set of doctrines the odium already attaching to quasi-atheistic Positivism; while on the other hand, the disciples of Comte are not unnaturally eager to claim for themselves every kind of modern thinking that can by any colourable pretext be annexed to their own province. The theological magazine-writer, who perhaps does not know what is meant by the Relativity of Knowledge but feels that there is something to be dreaded in Mr. Mansel's negations, finds an excellent substitute for intelligent criticism in the insinuation that this doctrine of relativity is a device of the Positivists, who refuse to admit the existence of God, and worship Humanity "symbolized as a woman of thirty, with a child in her arms." In similar wise the ardent disciple of Comte — who, so far as my experience goes, is not unlikely to be quite as narrow-minded as any theologian — is wont to claim all contemporary scientific thinkers as the intellectual offspring of his master, until their openly expressed dissent has reduced him to the alternative of stigmatizing them as "metaphysical;" very much as the Pope lays claim to the possession of all duly baptized Christians,[1] save those whom it has become necessary to excommunicate and give over to the Devil.

But aside from these circumstances, which partly explain the popular tendency to classify all scientific thinkers as Positivists, it is not to be denied that there are really plausible reasons why the Positive Philosophy should currently be regarded as representative of that whole genus of contemporary thinking which repudiates the subjective method, and, as Mr. Spencer says, "prefers proved facts to superstitions." As I have already shown, it was Comte who first inaugurated a scheme of philosophy explicitly

[1] See the amusing letter of Pius IX. to the Emperor of Germany, dated August 7, 1873.

based upon the utter rejection of anthropomorphism and the adoption of none but scientific doctrines and methods. I have already pointed out how great are our obligations to him for this important work, and I need not repeat the acknowledgment. For this reason it is obvious that whenever the theological thinker encounters a system which as far as possible rejects anthropomorphic interpretations, and whenever the metaphysician encounters a system which denies the validity of his subjective method, both the one and the other will quite naturally regard this system as some phase of Positivism. For the same reason, when we remember how strong is the tendency to "read between the lines" of any system of thought and thus to interpret it in accordance with our preconceptions, we shall see how easy it is for those who first derived from Comte their notions of scientific method and of the limits of philosophic inquiry, to "read into" his system all the later results of their intellectual experience, and thus to persist in regarding the whole as Positive Philosophy. Of this tendency it seems to me that we have an illustrious example in Mr. Lewes, the learned historian of philosophy and acute critic of Kant, who in the latest edition of his "History" still maintains that the agreement between Comte and Spencer is an agreement in fundamentals, while the differences between them are non-essential differences. That I am not incapable of understanding and sympathizing with this tendency, may be inferred from the fact that during eleven years I espoused the same plausible error, and called myself a Positivist (though *never* a follower of Comte) in the same breath in which I defended doctrines that are utterly incompatible with Positivism in any legitimate sense of the word. So long as we allow our associations with the *words* to colour and distort our scrutiny of the *things*, — a besetting sin of human philosophizing from which none of us can hope to have entirely freed himself, — so long it is possible for us to construct an apparently powerful argument in behalf of the fundamental agreement between Spencer and Comte. It may be said, for example, that both philosophers agree in asserting:

I. That all knowledge is relative;

II. That all unverifiable hypotheses are inadmissible;

III. That the evolution of philosophy, whatever else it may be, has been a process of deanthropomorphization;

IV. That philosophy is a coherent organization of scientific doctrines and methods;

V. That the critical attitude of philosophy is not destructive but constructive, not iconoclastic but conservative, not negative but positive.

Still confining our attention to the form of these propositions, and neglecting for the moment the very different meanings with which they would be enunciated respectively by the Cosmist and by the Positivist, it is open to us to maintain that, in asserting these propositions, Mr. Spencer agrees with Comte in asserting the five cardinal theorems of Positive Philosophy. Looking at the matter in this light, we might complain that Mr. Spencer, in his "Reasons for Dissenting, etc.," accentuates the less fundamental points in which he differs from Comte, and passes without emphasis the more fundamental points in which he agrees with Comte. We might urge that while the "Law of the Three Stages" is undoubtedly incorrect, nevertheless the essential point is that men's conceptions of Cause have been becoming ever less and less anthropomorphic. And similarly, when Mr. Spencer insists that Comte has not classified the sciences correctly, we might reply that, if we were to question M. Littré (who still holds to the chief positions of the Comtean classification), he would perforce admit that the fundamental point — the ground-question, as Germans say — is not whether physics comes after astronomy, or whether biology is an abstract science, but whether or not the sciences can be made to furnish all the materials for a complete and unified conception of the world.

In this statement of the case, which once seemed to me satisfactory, we have probably the strongest argument that can be devised in favour of the identification of Mr. Spencer's philosophy with Positivism. Yet, — as above hinted, and as will be self-evident to every one who has comprehended the foregoing chapters, — its apparent strength rests entirely upon the verbal ambiguity of the five cardinal propositions, which are stated in such a way as to conceal the real points at issue between the two philosophies. With regard to the first two propositions, I have already shown that they are in nowise so peculiar to Comte that allegiance to them should make us his disciples or coadjutors. In accepting the Doctrine of Relativity, as well as in receiving from modern science the inheritance of the Objective Method, we are the "heirs of all the ages," and are in nowise especially beholden to Comte. As regards the fifth proposition, concerning the critical attitude of philosophy, the discussion of it does not belong to our Prolegomena but to our Corollaries, since before we can comprehend it we must make sure that we understand what is implied by the Doctrine of Evolution. In the concluding chapter of this work it will appear that our dissent from Positivism is practically no less emphatic in respect to the critical attitude of philosophy than in other respects. For the present we can willingly dispense with this proof, as our point will be quite sufficiently established by an examination of the third and fourth propositions above alleged as cardinal alike to Positivism and to Cosmism.

And first, as regards the fourth proposition, the preceding chapter showed that Comte's conception of the scope and functions of philosophy was by no means the same as that which lies at the bottom of the present work. We have seen that he treated philosophy as merely an Organon of scientific methods, and totally ignored the conception of philosophy as a Synthesis of truths concerning the Cosmos. Now in order to comprehend the full purport of this, we must ask what was Comte's aim in constructing a system of philosophy? *To what end was this elaborate Organon devised?* It was not devised for the purpose of aiding the systematic exploration of nature in all directions, for we have seen that Comte began by discouraging and ended by anathematizing a large class of most important inquiries, chiefly on the ground of their "vainness" or "inutility." To understand the purpose of all this admirable treatment of philosophy as an Organon, we must take into account the statement of Dr. Bridges that Comte's philosophic aims were not different in his later epoch from what they had been in the earlier part of his career. From the very outset Comte intended to crown his work of reorganizing philosophy by constructing a polity which should be competent to reorganize society. The belief that society can be regenerated by philosophy is a belief which underlies all his speculations from first to last. His aims were as practical as those of Saint-Simon and Fourier, the difference being chiefly that these unscientific dreamers built their utopias upon abstract theories of human nature, while Comte sought to found his polity upon the scientific study of the actual tendencies of humanity as determined by its past history. In a future chapter I shall have occasion to show that this whole attempt of Comte's was based upon a profound misconception of the true state of the case. For the present we need only observe that with Comte the construction of a Philosophy meant ultimately the construction of a Sociology, to which all his elaborate systematization of scientific methods was intended to be ancillary. Why must we study observation in astronomy, experiment in physics and chemistry, comparison in biology? In order, says Comte, to acquire the needful mental training for sound theorizing in sociology. To him the various physical sciences were not sources from which grand generalizations were to be derived, embracing the remotest and most subtle phenomena of the Universe; they were whetstones upon which to grind the logical implements to be used in constructing a theory of Humanity. All other theorizing was to be condemned, save in so far as it could be shown to be in some way subservient to this purpose. Thus Comte's conception of philosophy was throughout anthropocentric, and he utterly ignored the cosmic point of view. There can be little doubt that he who, in 1830, rejected the development-theory, which a more prescient thinker, like Goethe, was enthusiastically proclaiming, would have scorned as chimerical and useless Mr. Spencer's theory of evolution. We may now begin to see why Comte wished to separate Man from the rest of the organic creation, and why he was so eager to condemn sidereal astronomy, the study of which tends in one sense to dwarf our conceptions of Humanity. Comte was indeed too much of an astronomer to retreat upon the Ptolemaic theory, but in his later works he shows symptoms of a feeling like that which actuated Hegel, when he openly regretted the overthrow of the ancient astronomy, because it was more dignified for man to occupy the centre of the universe! It is true that in his first great work Comte points out the absurdity of the theological view of man's supremacy in the universe, and rightly ascribes to the Copernican revolution a considerable share in the overthrowing of this view, and of the doctrine of final causes, with which it is linked. In spite of all this, however, and in spite of his admirable scientific preparation, Comte's conception of philosophy as the summary of a hierarchy of sciences, presided over by sociology, led him irresistibly toward the anthropocentric point of view; and so, when it became necessary for him to crown his work by indicating its relations to religion, he arrived, logically enough, at a Religion of Humanity, although in order to reach such a terminus he was obliged to throw his original Positivism overboard and follow the subjective method. In view then of all this complicated difference between the Positivist conception of philosophy and the conception expounded in this work, I think we are quite justified in designating our own conception by a different and characteristic name.

But the most fatal and irreconcilable divergence appears when we come to consider the third cardinal proposition, — that which relates to deanthropomorphization. If we inquire how it was that Comte was enabled to perpetrate, in the name of philosophy, such a prodigious piece of absurdity as the deification of Humanity, we shall find the explanation to lie in his misconception of what is meant by the relativity of knowledge. A good illustration of his confused thinking on this subject, to which I have already had occasion to refer, is afforded by his treatment of atheism. Comte had no patience with atheists, because of the chiefly negative and destructive character of the atheistic philosophy dominant in the eighteenth century. But when he lets us into his philosophic reasons for rejecting atheism, we find him complaining of the atheists, not because of their denial of Deity, nor because their doctrine contravenes the relativity of knowledge, but because they indulge in "metaphysical attempts to explain the origin of life upon the earth's surface." (!) On reading such passages, it becomes sufficiently evident that Comte did not really understand why metaphysical inquiries are illegitimate, but rejected them very much as the general reader might reject them, because they muddled his mind; and we may acknowledge the justice of Professor Huxley's sarcasm, that "metaphysics" is with Comte a "general term of abuse for anything that he does not like." Certain it is that Comte never understood the true import of the doctrine of relativity, as it is stated in our fourth chapter, — that there exists an Unknowable Reality, of which all phenomena, as presented in consciousness, are the knowable manifestations. As I have already observed, his most illustrious follower, M. Littré, unreservedly stigmatizes as "metaphysical" this very doctrine of the Unknowable, upon which the Cosmic Philosophy bases its rejection of metaphysics. Had Comte ever understood this doctrine, he would neither have sought to impose upon us a phenomenal God, in the form of idealized Humanity, nor would he have virtually abandoned his original Positivism in the wild attempt to "regenerate" the subjective method. All these things show that Comte never really fathomed the distinction between metaphysics and science; and as the final outcome of all this complicated misconception, we find him, in his famous "Law of the Three Stages," setting forth as the goal of all speculative progress a state or habitude of mind which never has existed and which never can exist. Herein the antagonism between Cosmism and Positivism becomes so fundamental as to outweigh all minor points of agreement, even were the points of agreement ten times as numerous as they are. For since we deny that the Positive mode of philosophizing, implying the recognition of nothing beyond the contents of observed facts, is a practicable mode at all, it is clear that we cannot, save by the utter distortion and perversion of human speech, be classified as Positivists.

Casting aside, then, our third and fourth cardinal propositions, temporarily assumed for the purpose of emphasizing this rejection of them, we may briefly restate as follows the fundamental issue between Cosmism and Positivism.

We have seen that Comte discerned the fact that there has been a continuous progress in men's conceptions, of which the chief symptom has been deanthropomorphization, and of which the result must be the destruction of ontology. He also discerned the fact, that after giving up ontology, it is still possible to build up a philosophy out of materials furnished by the sciences. We have freely admitted that, in each of these cases, the step taken by Comte was sufficient to work a revolution in the attitude of philosophy; and we may add that, by virtue of this twofold advance, Comte was justified in calling his system of philosophy "positive," in contrast with the absolutely sceptical or "negative" philosophy of the eighteenth century.

But, while admitting all this, we have also seen that Comte supposed the terminal phase of deanthropomorphization to consist in the ignoring of an Absolute Power manifested in the world of phenomena; and that he regarded philosophy merely as an Organon of scientific methods and doctrines useful in constructing a theory of Humanity and a social Polity. On the other hand, the Cosmic Philosophy is founded upon the recognition of an Absolute Power manifested in and through the world of phenomena; and it consists in a Synthesis of scientific truths into a Universal Science dealing with the order of the phenomenal manifestations of the Absolute Power. And manifestly these differences between the two systems of philosophy constitute an antagonism which is fundamental and irreconcilable. If the Positivist conception of philosophy be true, then the work which I am now writing is founded upon a baseless metaphysical fallacy; and conversely it is impossible to accept the doctrine expounded in this work, without *ipso facto* declaring the main position of Positivism to be untenable.

I shall hereafter have occasion to examine the views concerning Psychology, Sociology, Religion, and Practice, which are characteristic of the Positive Philosophy; and, as heretofore, while dissenting from those views in every instance, I shall have no hesitation in acknowledging their merits or in assigning a full meed of homage to the great thinker by whom they were propounded. But while my dissent upon all these points will serve to emphasize and illustrate the fundamental dissent declared in these Prolegomena, it will not be needful again to demonstrate in detail that we are not adherents of the Positive Philosophy. With thrice-reiterated argument, and at the risk of wearying the reader, it has now been made sufficiently evident that Cosmism and Positivism, far from being identical or identifiable with each other, are in a certain sense the two opposite poles of scientific philosophizing. And in virtue of this demonstrated antagonism, the divergences hereafter to be signalized will appear not merely as easily intelligible but even as *a priori* inevitable.

## CHAPTER XI

## THE QUESTION STATED

WE have now accomplished our preliminary task of defining and illustrating the scope and methods of Cosmic Philosophy, and are prepared to begin the work of constructing a theory of the universe out of the elements which science can furnish. It will accordingly become necessary for us to pass in review the sciences systematized in the eighth chapter, that we may be enabled to contemplate the widest truths which they severally reveal, as corollaries of some ultimate truth. In undertaking this task, there are two opposite courses, either of which we might pursue, though with differing degrees and kinds of success. On the one hand, we might begin with a survey of the concrete sciences; and having ascertained the most general truths respectively formulated by astronomy, geology, biology, psychology, and sociology, we might interpret all these truths in common by merging them all in a single widest generalization concerning the concrete universe as a whole; and lastly, through an analysis of this widest generalization we might seek the ultimate axiom by which the validity of our conclusions is certified. Or, on the other hand, we might begin by searching directly for this ultimate axiom; and having found it, we might proceed to deduce from it that widest generalization which interprets the most general truths severally formulated by the concrete sciences; and finally, by the help of these universal principles, we might perhaps succeed in eliciting sundry generalizations concerning particular groups of concrete phenomena which might otherwise escape our scrutiny.

The latter, or synthetic method of procedure, is much better adapted for our present purpose than the former, or analytic method. Indeed the mass of phenomena with which we are required to deal is so vast and so heterogeneous, the various generalizations which we are required to interpret in common are apparently so little related to one another, that it may well be doubted if the appliances of simple induction and analysis would ever suffice to bring us within sight of our prescribed goal. The history of scientific discovery affords numerous illustrations — and nowhere more convincingly than in the sublime chapter which tells the triumph of the Newtonian astronomy — of the comparative helplessness of mere induction where the phenomena to be explained are numerous and complicated. A simple tabulation and analysis of the planetary movements would never have disclosed, even to Newton's penetrating gaze, the law of dynamics to which those movements conform. But in these complicated cases, where induction has remained hopelessly embarrassed, the most brilliant success has often resulted from the adoption of a hypothesis by which the phenomena have been deductively interpreted, and which has been uniformly corroborated by subsequent inductions. The essential requisite in such an hypothesis is that it must have been framed in rigorous conformity to the requirements of the objective method. It must be based upon properties of matter or principles of dynamics that have previously been established or fully confirmed by induction ; it must appeal to no unknown agency, nor invoke any unknown attribute of matter or motion ; and it must admit ultimately of inductive verification. Such a hypothesis, in short, is admissible only when it contains no unverifiable element. And of hypotheses framed in accordance with these rigorous requirements, the surest mark of genuineness is usually that they are not only uniformly verified by the phenomena which first suggested them, but also help us to the detection of other relations among phenomena which would otherwise have remained hidden from us.

In conformity, then, to these requirements of scientific method, our course is clearly marked out for us. We have first to search, among truths already indisputably established, for that ultimate truth which must underlie our Synthesis of scientific truths. We have next to show how the widest generalization which has yet been reached concerning the concrete universe as a whole, may be proved to follow, as an inevitable corollary, from this ultimate truth. This widest generalization will thus appear, in the light of our demonstration, as a legitimate hypothesis, which we may verify by showing that the widest generalizations severally obtainable in the concrete sciences are included in it and receive their common interpretation from it. Throughout the earlier part of this special verification, in which we shall be called upon to survey the truths furnished respectively by astronomy, geology, biology, and psychology, I shall follow closely in the footsteps of Mr. Spencer, who has already elaborately illustrated these truths in the light of the Doctrine of Evolution. When we arrive at sociology — still following Mr. Spencer's guidance, but venturing into a region which he has as yet but cursorily and fragmentarily surveyed for us — I shall endeavour to show that our main hypothesis presents the strongest indications of its genuineness by affording a brilliant interpretation of sundry social phenomena never before grouped together under a general law. This interpretation I shall then seek further to verify by showing how it includes and justifies whatever is defensible in the generalizations which such writers as Comte and Buckle have obtained from an inductive survey of the facts of human history. Finally I shall apply our central hypothesis to the special problem of the Origin of Man, and show how, from its marvellous success in dealing with the difficult questions of intellectual and moral progressiveness, the Doctrine of Evolution must be pronounced to have sustained the severest test of verification which our present scientific resources enable us to apply upon this great scale. With this most significant and interesting inquiry, our Synthesis of scientific doctrines will be completed. Such ultimate questions as must inevitably be suggested on our route — questions concerning the relations of the Doctrine of Evolution to Religion and Ethics — will be considered, with the help of the general principles then at our command, in the Corollaries which are to follow.

At present, however, we are not at the goal, but at the starting-point of this arduous course; and our attention must first be directed to the search for that ultimate axiom upon which our Synthesis must rest. Where now shall we begin? In what class of sciences are we to look for our primordial principle? The above survey of our projected course has already assured us that we need not search for it among the concrete sciences. Obviously the widest proposition which can possibly be furnished by astronomy or biology, or any other concrete science, cannot be wide enough to underlie a Synthesis of all the sciences. The most general theorems of biology are not deducible from the most general theorems of astronomy; nor *vice versa.* But the most general theorems of each concrete science are ultimately deducible from theorems lying outside the region of concrete science. Where shall we find such theorems? If we turn to the purely abstract sciences — logic and mathematics — we shall get but little help. Useful as these sciences are, as engines of investigation, they do not contain what we are now looking for. Obviously mathematics, dealing only with relations of number, form, and magnitude, cannot supply the ultimate principle from which may be deduced such phenomena as the condensation of a nebula, the segmentation of an ovum, or the development of a tribal community. To build a system of philosophy upon any possible theorem of mathematics would only be to repeat, after twenty-four centuries, the errors of Pythagoras. And the helplessness of abstract logic, for our purposes, is too manifest to need illustration.

Let us then turn to the abstract-concrete sciences; for in the widest generalizations at which these sciences have jointly arrived we must find, if anywhere, the theorem which we desire. I say "jointly," for in the deepest sense the subject-matter is the same, in molar physics, in molecular physics, and in chemistry. All three sciences deal, in one way or another, with the most general laws of those redistributions of matter and motion which are continually going on throughout the knowable universe. The first deals with the movements of masses; the second deals with movements of molecules, and with the laws of aggregation of molecules that are homogeneous; the third deals with the laws of aggregation of molecules that are heterogeneous. In either case the phenomena dealt with are movements of matter, whether movements of translation through space, or movements of undulation among molecules, or movements whose conspicuous symptom is change of physical state or of chemical constitution. The widest theorems, therefore, which the three abstract-concrete sciences can unite in affirming, must be universal propositions concerning Matter and Motion.

Obviously it is in this region of science that we must look for our primordial theorem. But little reflection is needed to convince us that all the truths attainable by the concrete sciences must ultimately rest upon truths relating to the movements of matter. It is with the movements, actual or inferred, of certain specific masses of matter, that astronomy in both its branches is concerned. Movements of matter, likewise, in a specific region of the universe, and under specific conditions characteristic of this region, constitute the facts about which geology speculates. We need but remember that nutrition is at bottom merely a process in which certain molecules shift their positions, and that the life of an organism is simply a long-continued series of adjustments and readjustments among mutually related and mutually influencing systems of aggregated molecules, in order to see that the fundamental laws of the movements of matter must underlie biology also. And although the phenomena of mind — whether manifested in individuals or in communities — cannot be explained as movements of matter; yet, as will be hereafter shown, there is no mental phenomenon which does not involve, as its material correlate, some chemical change in nerve-tissue consisting in a redistribution of molecules; so that in psychology and sociology likewise, our conclusions must become ultimately implicated with theorems concerning matter and motion. Thus in every department of concrete science, the leading problem is in some way or other, either directly or indirectly or very remotely, concerned with distributions and redistributions of matter and motion; and in all our specific conclusions some general conclusion relating to movements of matter must be directly or indirectly or very remotely involved.

Our course is thus still more definitely marked out. We must first search for the deepest attainable truth respecting matter and motion abstractly considered. We must pursue this truth and its corollaries, among the most general groups of phenomena in which these corollaries are exemplified, until we arrive at some concrete result concerning the most general aspects of that redistribution of matter and motion which is everywhere going on. And upon this concrete result we shall find that universal generalization to be based, the validity of which we have afterwards to certify by its agreement with inductions drawn from the several groups of phenomena with which the concrete sciences deal.

Here, before proceeding further, we may fitly pause for a moment, to relieve a puzzling doubt which may ere this have disturbed the mind of the reader. Did we not elaborately prove, in our opening chapter, that concerning the movements of molecules and their aggregation into masses, not only nothing can be known, but no tenable hypothesis can be framed? Did we not, with full knowledge of what we were doing, hang up as the very sign-board of our *φροντιστήριον* or philosophy-shop, the proposition that all that either sense or reason can tell us concerning the intimate structure of a block of wood is utterly and hopelessly delusive? Did we not show that the hypothesis of attractive and repulsive forces lands us straightway in an insoluble contradiction? Did we not find it impossible to get rid of the difficulties which surround the conception of an atom or a molecule, whether regarded as divisible or as indivisible? And did we not conclude that the conception of matter acting upon matter is a pseud-conception which can by no effort be construed in consciousness?—Yet in spite of all this, it may be said, we are about to base the entire following Synthesis upon preliminary conclusions relating to the movements of molecules and their aggregation into masses; we are likely to draw inferences from the assumed intimate structure of certain bodies; we have inevitably to make use of the hypothesis of attractive and repulsive forces; we shall constantly have tacit reference to the conception of atoms and molecules; and we shall be obliged to take account of matter as constrained in its movements by other neighbouring matter. Is there not here, it may be asked, a *reductio ad absurdum*, either of the Synthesis which is to follow, or of the initial arguments upon which the claims of such a Synthesis to stand for the whole of attainable philosophy were partly based?

I state this dilemma as strongly as possible, because it forcibly illustrates the omnipresence of Mystery,—because it shows how, beneath every physical problem, there lies a metaphysical problem whereof no human cunning can detect the solution. Practically, however, the avenue of escape has sometime since been implicitly indicated,—in the fifth and sixth chapters of these Prolegomena. In the chapter on Causation it was shown that, though we can in nowise conceive matter as acting upon matter, yet, for the purposes of common-sense, of science and of philosophy, it is quite enough that one kind of phenomenal manifestation is invariably and unconditionally succeeded by some other kind of phenomenal manifestation. And in characterizing the Subjective and Objective Methods, we saw that the truth of any proposition, for scientific purposes, is determined by its agreement with observed phenomena, and not by its congruity with some assumed metaphysical basis. For example, the entire Newtonian astronomy—the most elaborate and finished scientific achievement of the human mind—rests upon a hypothesis which, if metaphysically interpreted, is simply inconceivable. The conception of matter attracting matter through an intervening tract of emptiness is a conception which it is impossible to frame,—and Newton knew it, or felt it to be so. But nowhere did his unrivalled wisdom show itself more impressively than in this,—that he accurately discriminated between the requirements of science and the requirements of metaphysics, and clearly saw that, while metaphysics is satisfied with nothing short of absolute subjective congruity, it is quite enough for a scientific hypothesis that it gives a correct description of the observed coexistences and sequences among phenomena.[1] In truth, for scientific purposes, we are no more required to conceive the action of matter upon matter in the case of gravitation than in any other case of physical causation. All that the hypothesis really asserts is that matter, in the presence of other matter, will alter its space relations in a specified way; and there is no reference whatever to any metaphysical *occulta vis* which passes from matter in one place to matter in another place.

There is, however, no good ground for objecting to the use of the phrase "attraction," provided it be employed only as a scientific artifice. There is a certain sense in which sci-

[1] This is distinctly stated by Copernicus: "Neque enim necesse est eas hypotheses esse veras, imo ne verisimile quidem, sed sufficit hoc unum, si calculum observationibus congruentem exhibeant." See Lewes, *Aristotle*, p. 92; *Problems of Life and Mind*, vol. i. p. 317.

ence, as well as legal practice, has its "fictions" that are eminently useful. The lines and circles with which geometry deals have nothing answering to them in nature; and the analyst employs a "scientific fiction" when he deals with infinitesimals, since it is impossible to conceive a quantity less than any assignable quantity. In like manner, there is nothing objectionable in using language which assimilates the case of a planet revolving about the sun to the case of a stone whirled at the end of a string; for there is real similarity between the phenomena. So if the science of chemistry had been obliged to wait until all the metaphysical difficulties which encompass the conception of a molecule or an atom had been cleared away, it might well have waited until the end of the world. Quite likely the "atom" in chemistry is as much a "scientific fiction" as the "infinitesimal" in algebra; but we cannot therefore complain of the chemist for assigning to it shape and dimensions, provided he makes a scientific and not a metaphysical use of the artifice. In the region of science such a fiction is no more illegitimate than that fiction in the region of common-sense by which I judge this writing-table to be solid, while, for aught I know to the contrary, the empty spaces between its particles may be as much greater than the particles as the interstellar spaces are greater than the stars. We need have no hesitation, therefore, in dealing with the aggregations of atoms and molecules, after the manner of the chemical philosopher, or with attractive and repulsive forces, after the manner of the physicist, so long as we take care that the substance of our propositions has reference only to verifiable coexistences and sequences among phenomena.

Another possible difficulty may be now more summarily disposed of. If it be urged that to frame a "generalization concerning the concrete universe as a whole" is manifestly to transgress the limits of sound philosophizing, since we can never know but a tiny portion of the concrete universe, and can never even know how much there is that lies beyond our ken; if such an objection be urged against the undertaking planned in the present chapter, we may again appeal to Newton as witness in our favour. The law of gravitation is expressed in terms that are strictly universal, — terms which imply that wherever matter exists, be it a million times more remote than the outermost limit of telescopic vision, the phenomena of gravitation must be manifested. Comte, indeed, questioned the legitimacy of extending the generalization beyond the limits of the solar system. But his doubt, which facts so soon refuted, was based on inadequate knowledge of the psychological aspect of the case. Newton's hypothesis simply detected and generalized the mode of manifestation of one of those properties by virtue of which matter is matter; and he was justified, according to the principles laid down in our third chapter, in basing a universal proposition upon a single instance. The final test of the presence of matter is the manifestation of the gravitative tendency; and such must be the case so long as we are unable to transcend experience. As I before observed, it is quite possible that there may be worlds in which numerical limitations like ours are not binding, and so it is very possible that there may be worlds in which there is neither matter nor gravity. But any such possible worlds, standing entirely out of relation to our experience, are practically non-existent for a philosophy which is based on the organization of experience.

Now, though the law of evolution is not, like the law of gravitation, the generalization of a property of matter, it is still the generalization of certain concrete results of known properties of matter. And the universality which in the following chapters will be claimed for this generalization is precisely like the universality claimed for the law of gravitation. The law of evolution professes to formulate the essential characteristics of a ceaseless redistribution of matter and motion that must go on wherever matter and motion possess the attributes by which we know them. In Mr. Mill's hypothetical world where two and two make five, the law of evolution may not hold sway. But within the limits of our experience, the law is a "generalization concerning the concrete universe as a whole;" and if it be satisfactorily verified, we shall have achieved that organization of scientific truths into a coherent body of doctrine which has been shown to be the legitimate aim of Philosophy.

Here in conclusion we may again call attention to the significance of the phrase by which I have designated the kind of philosophy that is expounded in this work. We may reiterate the statement, which has already been illustrated from various points of view, that our philosophy is peculiarly entitled to the name of Cosmic Philosophy. For while it may be urged that earlier philosophies have also been cosmic, in so far as they have sought to offer some explanation of the universe, on the other hand it must be acknowledged that never before has the business of philosophy, regarded as a theory of the universe, been undertaken with so clear and distinct a conception of its true scope and limitations. Though other thinkers, before Mr. Spencer, may have generalized about the concrete universe as a whole, it cannot be denied that he has been the first to frame a verifiable hypothesis upon this stupendous scale. The law of evolution is the first generalization concerning the concrete universe as a whole, which has been framed in conscious conformity to the rigorous requirements of the objective method, and which has therefore served to realize the prophetic dream of Bacon, by presenting Philosophy as an organism of which the various sciences are members. Obviously a system which has achieved, or consciously sought to achieve, such a result, is entitled *par excellence* to the name of Cosmic Philosophy. It has been the first to give practical realization to that sublime thought of two master minds, which I have inscribed at the head of this work: —

"To a thinker capable of comprehending it from a single point of view, the universe would present but a single fact, but one all-comprehensive truth; and it is for this reason that we call it Cosmos, and not chaos."

# PART II

## SYNTHESIS

"Je unvollkommener das Geschöpf ist, desto mehr sind diese Theile einander gleich oder ähnlich, und desto mehr gleichen sie dem Ganzen. Je vollkommener das Geschöpf wird, desto unähnlicher werden die Theile einander. Je ähnlicher die Theile einander sind, desto weniger sind sie einander subordinirt. Die subordination der Theile deutet auf ein vollkommneres Geschöpf." — GOETHE, *Zur Morphologie*. 1807.

# CHAPTER I

## MATTER, MOTION, AND FORCE[1]

IN the third book of the "Philosophie Positive," Comte observes that it can hardly be by accident that the word "Physics," which originally denoted the study of the whole of nature, should have become restricted to that science which deals with the most abstract and general laws of the rearrangement of Matter and Motion. This is one of the many profound remarks scattered through Comte's writings, the full significance of which he could hardly himself have realized.[2] For it will now appear — as the preceding chapter taught us to expect — that the study of Physics (including under that name,

[1] [See Introduction, § 15.]

[2] For immediately afterwards we find Comte basing the organic sciences upon physics, but excluding astronomy, which he calls an "emanation from mathematics." It is indeed difficult to see how astronomy, which involves the physical ideas of matter, motion, and force, can be an emanation from mathematics, which involves only the purely abstract ideas of space and number. In fact, as above shown (Part I. chap. viii.), astronomy, no less than the other concrete sciences, is dependent upon physics. Here, as elsewhere, Comte was misled by his serial arrangement.

for the moment, the three abstract-concrete sciences) underlies the study of the whole of nature, and discloses those universal truths upon which a Synthesis of the widest truths disclosed by the concrete sciences must repose. It investigates the general phenomena of matter, motion, and force; while the concrete sciences investigate these phenomena as manifested in particular groups of aggregates. The primordial axiom, upon which our synthetic study of the universe must be founded, is one which is disclosed by the analytic study of the movements of masses and molecules. And thus the threefold classification of the sciences, by which we found it necessary to replace the simple linear classification of Comte, will find itself practically justified in the very first step which we take toward the organization of scientific truths into a system of Cosmic Philosophy.

/ For at the bottom alike of molar physics, of molecular physics, and of chemistry, there lie, in fact, two universal propositions, — the one relating to Matter, the other relating to Motion. These are the familiar propositions that *Matter is indestructible*, and that *Motion is continuous*. Upon the truth of this pair of closely related propositions depends the validity of every conclusion to which chemistry or either branch of physics can attain. If, instead of dealing with unalterable quantities and weights, the chemist and physicist "had to deal with quantities and weights which were apt, wholly or in part, to be annihilated, there would be introduced an incalculable element, fatal to all positive conclusions." And since motions of masses and molecules form a principal part of the subject-matter of the three abstract-concrete sciences, it is obvious that "if these motions might either proceed from nothing or lapse into nothing, there would be an end to scientific interpretation of them;" no science of chemistry, or of physics, molecular or molar, would be possible.

The evidence which has secured universal acceptance for these twin theorems has been chiefly inductive evidence. The ancients freely admitted that matter might be created and destroyed; and until the time of Galileo it was supposed that moving bodies had a natural tendency to lose their motion by degrees until they finally stopped. Falsifying many of the complex conditions in the case, the ancients verbally maintained the negations of the theorems that matter is indestructible and motion continuous; although, if they had tried to realize in thought their crude propositions, they would have found it impossible. But gradually it began to be perceived that in all cases where matter disappears — as in the burning of wood or the evaporation of water — the vanished matter has only undergone a molecular change which renders it temporarily imperceptible by our unaided senses. Of the manner in which quantitative chemistry has demonstrated this truth, pursuing, balance in hand, the vanished matter through all its protean transformations, it is unnecessary to speak. Similar has been the evidence in the case of motion. Observing that, the more effectually friction, atmospheric resistance, and other obstacles to the visible continuance of motion are eliminated, the longer the motion continues, the conclusion was reached, by the method of concomitant variations, that if all obstacles could be eliminated, the motion would continue forever. Finally, when it was shown that the apparent loss of motion caused by friction is, in fact, only a transformation of a certain quantity of molar motion into its equivalent quantity of that species of molecular motion known as heat, it was admitted on all sides that motion is indestructible, as well as matter.

But a brief analysis will show that the twin theorems which we are considering have a deductive warrant equally valid with their inductive warrant. Deep as are the truths that matter is indestructible and motion continuous, there is a yet deeper truth implied by these two. These theorems are not fundamental, but derivative; and it therefore becomes necessary to ascertain the axiom upon which they depend, since here, if anywhere, must be found the primordial truth which we are seeking.

Since we cognize any portion of matter whatever only as an aggregate of coexistent positions which offer resistance to our muscular energies; since it is primarily by virtue of such resistance that we distinguish matter from empty space; it follows that our idea of matter is built up of experiences of force, and that the indestructible element in matter is its resisting power, or the force which it exerts. Considering different portions of matter in their relations to each other, we are brought to the same conclusion. When we say that it is chemistry which has proved with the balance that no matter is ever annihilated, we imply that the test of the presence of matter is gravitative force, and that this force is proportional to the quantity of matter.

The case of motion is precisely similar. We cognize motion as the successive occupation of a series of positions by an aggregate of coexistent positions which offer resistance; and the essential element in the cognition — "the necessity which the moving body is under to go on changing its position" — has been proved to result from early experiences of force as manifested in the movements of our muscles. Consequently, as Mr. Spencer observes, when we find ourselves compelled to conceive motion as continuous, we find that what "defies suppression in thought is really the force which the motion indicates. The unceasing change of position, considered by itself, may be mentally abolished without difficulty. We can readily imagine retardation and stoppage to result from the action of external bodies. But to imagine this is not possible without an abstraction of the force implied by the motion. *We are obliged to conceive this force as impressed in the shape of reaction on the bodies that cause the arrest.*"[1]

Or to put the whole case briefly in another form: The fundamental elements of our conception of matter are its force-element and its space-element, namely, resistance and extension. The fundamental elements of our conception of motion are its force-element and its space-and-time-element, namely, energy and velocity. That in each case the force-element is primordial is shown by the facts that what we cannot conceive as diminished by the compression of matter is not its extension but its power of resistance; what we cannot conceive as diminished by the retardation of motion is not its velocity but its energy.

Therefore, in asserting that matter is indestructible and that motion is continuous, we assert, by implication, that force is persistent.

[1] [*First Principles*, § 59.]

Our two fundamental theorems are thus seen to derive their validity from a yet deeper theorem, — the proposition that the force manifested in the knowable universe is constant, can neither be increased nor diminished.

To this result, which we have here obtained through a general consideration of the problems treated by the abstract-concrete sciences, we shall be equally led by any special question of molar physics, molecular physics, or chemistry which we may choose to analyze. When we say that the curve described by a cascade in leaping from a projecting ledge of rock is a parabola of which the coördinates express respectively the momentum of the water and the intensity of gravity at the verge of the ledge; or when we say that the line followed by any solid body, drawn by two differently situated forces, is the diagonal of a parallelogram of which the sides express the respective intensities of the forces; the validity of our assertion depends entirely upon the postulate that the forces in question are constant in amount. Annihilate a single unit of force, and our proposition is hopelessly falsified. Similarly in molecular physics, when we enunciate the formula by means of which Joseph Fourier founded the mathematical theory of heat — namely, the formula that, in all cases of radiation and conduction, the thermological action between two bodies is proportional to the difference of their temperatures — we imply that action and reaction are always equal between the systems of molecules which compose the two bodies. And the equality of action and reaction between systems of atoms is taken for granted in every proposition of chemistry; as, for instance, when we say that it will take four molecules of any monatomic substance, like hydrogen, to saturate a single molecule of any tetratomic substance, like carbon. Now to assert the equality of action and reaction, whether between masses, molecules, or atoms, is to assert that force is persistent. "The allegation really amounts to this, that there cannot be an isolated force, beginning and ending in nothing; but that any force manifested, implies an equal antecedent force from which it is derived, and against which it is a reaction. Further, that the force so originating cannot disappear without result; but must expend itself in some other manifestation of force, which, in being produced, becomes its reaction; and so on continually."[1] Clearly, therefore, the assertion that force is persistent is the fundamental axiom of physics: it is the deepest truth which analytic science can disclose.

But now what warrant have we for this fundamental axiom? How do we know that force is persistent? If force is not persistent, if a sin-

[1] Spencer, *First Principles*, p. 188.

gle unit of force can ever be added to or subtracted from the sum total at any moment existing, our entire physical science is, as we have seen, a mere delusion. In such case, it is a delusion to believe that action and reaction are always equal, that the strongest bow, bent by the strongest muscles, will always send its arrow to the greatest distance if otherwise unimpeded — it is a delusion to believe that the pressure of the atmosphere and its temperature must always affect the height of enclosed columns of alcohol or mercury, or that a single molecule of nitrogen will always just suffice to saturate three molecules of chlorine. And this being the case, our concrete sciences also fall to the ground, and our confidence in the stability of nature is shown to be baseless; since for aught we can say to the contrary, the annihilation of a few units of the earth's centrifugal force may cause us to fall upon the sun to-morrow.

But how do we know that all science is not a delusion, since there still exist upon the earth's surface persons who will tell us that it is so? Why do we so obstinately refuse to doubt the constancy of the power manifested in nature? What proof have we that no force is ever created or destroyed?

Logically speaking, we have no proof. An axiom which lies below all framable propositions cannot be deductively demonstrated. Below the world stands the elephant on the back of the tortoise, and if under the tortoise we put the god Vishnu, where is Vishnu to get a foothold? Nor can our axiom be demonstrated inductively, without reasoning in a circle. We cannot adduce the observed equality of action and reaction in proof of the persistence of force, because this persistence is taken for granted in every observation by which the equality of action and reaction is determined. Obviously it is impossible to prove the truth of an axiom by any demonstration in every step of which the truth of the axiom must be assumed.

But these results need not surprise or disturb us. As we saw, when discussing the Test of Truth, the process of demonstration, which consists in continually "merging derivative truths in those wider and wider truths from which they are derived," must eventually reach a widest truth, which cannot be contained in or derived from any other. At the bottom of all demonstration there must lie an indemonstrable axiom. And the truth of this axiom can only be certified by the direct application of the test of inconceivability. We are compelled to believe in the persistence of force, because it is impossible to conceive a variation in the unit by which force is measured. It is impossible to conceive something becoming nothing or nothing becoming something, without establishing in thought an equation between something and nothing; and this cannot be done. That one is equal to zero is a proposition of which the subject and predicate will destroy each other sooner than be made to unite.

Thus the proof of our fundamental axiom is not logical, but psychological. And, as was formerly shown, this is the strongest possible kind of proof. Inasmuch as our capacity for conceiving any proposition is entirely dependent upon the manner in which objective experiences have registered themselves upon our minds, our utter inability to conceive a variation in the sum total of force implies that such variation is negatived by the whole history of the intercourse between the mind and its environment since intelligence first began. The inconceivability test of Kant and the experience test of Hume, when fused in this deeper synthesis, unite in declaring that the most irrefragable of truths is that which survives all possible changes in the conditions under which phenomena are manifested to us. The persistence of force, therefore, being an axiom which survives under all conditions cognizable by our intelligence, being indeed the ultimate test by which we are compelled to estimate the validity of any proposition whatever concerning any imaginable set of phenomena and under any conceivable circumstances, must be an axiom necessitated by the very constitution of the thinking mind, as perennial intercourse with the environment has moulded it.

Mr. Mill, indeed, in his "System of Logic," Book III. chapter xxi., maintains that our belief in the necessity and universality of causation (which was above shown[1] to be an immediate corollary from the persistence of force) rests upon an induction *per enumerationem simplicem*, which is, however, valid in this one case, because it is coextensive with all known orders of phenomena. The incompleteness of this view is shown by the fact that the persistence of force is necessarily assumed in every step of the vast induction by which the law of causation is said to be established. Mr. Mill only emphasizes the incompleteness of his view when he repudiates the inconceivability test as evidence of the law in question. This point has been already so fully discussed that little more need to be said about it here. When, in a future chapter, we come to deal especially with the evolution of intelligence, we shall see that Mr. Mill's inadequate treatment of this subject is due to imperfect mastery of the Doctrine of Evolution. We shall see that the so-called experience philosophy is both wider and deeper than English psychologists, from Hobbes to Mill, have imagined. We shall see that not only our ac-

[1] See above, Part I. chap. vi.

quired knowledge, but even the inherited constitution of our minds, is the product of accumulated and integrated experiences, partly personal but chiefly ancestral. Upon this wider ground we shall find ourselves able to dwell in peace with our old foes, the intuitionalists, since it will be seen that the very intuitions upon which they rightly insist as inexplicable from individual experience are nevertheless explicable from the organized experiences of countless generations. And the conclusion will then assert itself, with redoubled emphasis, that the axiom of the persistence of force, being the product of the entire intercourse between subject and object since the dawn of intelligence, must have the highest warrant which any axiom can have.

Let us for the present, however, content ourselves with reproducing the psychological argument by which Mr. Spencer clinches his demonstration of the necessity which we are under to conceive of force as persistent. "The indestructibility of matter and the continuity of motion we saw to be really corollaries from the impossibility of establishing in thought a relation between something and nothing. What we call the establishment of a relation in thought is the passage of the substance of consciousness from one form into another. To think of something becoming nothing would involve that this substance of consciousness, having just existed under a given form, should next assume no form; or should cease to be consciousness. And thus our inability to conceive matter and motion destroyed is our inability to suppress consciousness itself. What is thus proved true of matter and motion is *a fortiori* true of the force out of which our conceptions of matter and motion are built." Thus we see it is the persistence of consciousness itself which imposes on us the necessity of asserting the persistence of force. And accordingly this primordial axiom being involved in every act of conscious thinking, and being the basis of experience, "must be the basis of any scientific organization of experiences. To this an ultimate analysis brings us down; and on this a rational synthesis must build up."

The force of these considerations will become still more strikingly apparent as we proceed to contemplate the most general corollaries of this fundamental axiom with which the science of physics has furnished us. The first of these corollaries is the theorem that the relations among forces are persistent. That is to say, in all cases an aggregate of like causes will be followed by an aggregate of like effects. "If in any two cases there is exact likeness not only between those most conspicuous antecedents which we distinguish as the causes, but also between those accompanying antecedents which we call the conditions, we cannot affirm that the effects will differ, without affirming either that some force has come into existence or that some force has ceased to exist. If the coöperative forces in the one case are equal to those in the other, each to each, in distribution and amount, then it is impossible to conceive the product of their joint action in the one case as unlike that in the other, without conceiving one or more of the forces to have increased or diminished in quantity; and this is conceiving that force is not persistent."[1] It follows, therefore, from the persistence of force, that there is an invariable order of succession between the totality of phenomena which exist at any given instant and the totality of phenomena which exist at the next succeeding instant. No matter how many special orders of sequences may interlace to form the grand web of sequent phenomena, the order of sequences, both separately and in the aggregate, must be invariable. In complicated mechanical problems, where many forces are involved, we proceed to eliminate one after another by means of the principle of the parallelogram of forces, until at last we retain but two differently located forces, the resultant of which is easily calculable. So, in the most complex cases of causation to be found in nature — as, for instance, in those concerned in the develop-

[1] *First Principles*, p. 193.

ment of the moral character of individuals — if we possessed the means of measuring quantitatively the ratio of each set of antecedents to its set of consequents, we might eliminate one group after another, until at length a necessary relation of sequence would be disclosed between the resultant group of antecedents and consequents. As Mr. Mill observes: "For every event there exists some combination of objects or events, some given concurrence of circumstances, positive and negative, the occurrence of which is always followed by that phenomenon. We may not have found out what this concurrence of circumstances may be; but we never doubt that there is such a one, and that it never occurs without having the phenomenon in question as its effect or consequence."[1] Our unhesitating assurance that "there is a law to be found if we only knew how to find it" is thus the foundation of all the canons of inductive logic. The uniformity of the laws of nature is elsewhere called by Mr. Mill "the major premise of all inductions." The present analysis further shows us that this uniformity of law is resolvable into the persistence of relations among forces, and is therefore an immediate corollary from the persistence of force.

Besides this purely philosophical corollary from our fundamental axiom, we have to note

[1] *System of Logic*, 6th edition, vol. i. p. 367.

three other corollaries, which — as belonging to the transcendental regions of physical science — must be set forth and illustrated before we can profitably begin our synthesis of scientific truths: Let us briefly consider these in their natural order.

The first of these corollaries is the generalization currently known as the "Correlation of Forces." Since each manifestation of force must have been preceded by some other equivalent manifestation of force, it follows that when any specific manifestation appears to terminate, it does not really cease to exist, but is only transformed into some other specific manifestation. That we may better apprehend this important truth, let us clear away some of the ambiguity which surrounds the terms commonly employed in the statement of it. The phrase "correlation of forces," which means the correlation of sensible motion with heat, light, electricity, etc., implies that heat, light, and electricity are forces. This is not strictly accurate. Heat and light are modes of undulatory motion, and electricity, with its kindred phenomena, is to be similarly interpreted. Now motion is not force, but one of the manifestations of force; and so the various modes of motion, molar and molecular, are differently conditioned manifestations of force. The force which produces or resists motion is known by us only under the twofold form of attraction and repulsion, which may be either polar or universal. Polar attraction or repulsion is that which acts with different power in different directions. An example of polar attraction is to be found in every case of crystallization, where molecules are grouped into a solid figure bounded by plane surfaces; and a familiar example of polar repulsion is that which is exhibited when the positive poles of any two magnets are brought into mutual proximity. Universal attraction or repulsion is that which acts with equal power in all directions. In universal attraction we are accustomed to distinguish three modes, respectively called gravity, cohesion, and chemism or chemical affinity.

The essential difference between these modes of primary force and the various modes of motion is illustrated by the familiar facts that gravity causes molar motion while molar motion does not cause gravity; and that chemism gives rise to the species of molecular motion called heat, while heat cannot give rise to chemism, though it may result in a molecular rearrangement which will allow chemism to manifest itself. For example, gravity causes a spent rocket to fall to the ground; but the upward motion of the rocket does not cause gravity, although it results in a position of the rocket which enables gravity to reveal itself by causing downward motion. So when nitrous oxide is decomposed into nitrogen and oxygen, a considerable amount of heat is evolved; but when all this thermal undulation is restored under appropriate conditions, and the compound is again formed, it is not that the thermal undulation gives rise to the chemism which draws the atoms of nitrogen and oxygen together; it is only that the thermal undulation results in such a redistribution of the atoms that their progress toward each other is unimpeded, and thus the latent force of chemism is revealed.

Now the law of the correlation of forces, which perhaps ought rather to be called the law of the transformation of motion, is simply the obverse of that corollary from the persistence of force, which affirms that whatever energy has been expended in doing work must reappear as energy. The energy of molar motion which disappears when an arrow sticks in its target is really transformed into the energy of molecular motion which is recognized partly as heat and partly as electricity. That the different modes of motion are transformable into each other is now one of the commonplaces of physical science, and needs but little illustration here. What is called the arrest of motion by friction is now known to be the change of molar motion into heat, when the rubbing substances are alike in constitution, — into heat and electricity, when they are unlike. In violent collisions, as in the chipping of stones with a mason's chisel, the arrested molar motion is partially changed into light. And when an iron bar is suspended in the magnetic meridian and violently struck or continually jarred, a portion of the arrested motion reveals itself as magnetism.

The transformation of heat into molar motion may be seen in the rise and fall of the mercury in the thermometer, or in the driving of a piston by the molecular dilatation of aqueous vapour. When lime is introduced into an atmosphere of burning hydrogen, we see the conversion of heat into light. And when the heated ends of zinc and copper wires are brought together, we see heat generating electric currents. Conversely, electricity conducted down a lightning-rod is partly converted into heat; and in the bright flashes which are followed by claps of thunder, we witness electric energy partly consumed in originating light.

The phenomenon commonly called light is but a species of a mode of solar energy which may be called radiance or actinism, and which, according to the manner in which it affects our senses, is known as radiant heat, as light, or as the energy which works changes in the daguerreotype-plate and in the leaves of plants. The difference between the higher rays of the solar spectrum, which manifest themselves chiefly in causing chemical changes, and the lower rays, which are cognized as violet light, is generically the same as the difference between these and the still lower rays which are cognized as indigo, blue, green, yellow, orange, or red light; and the same is true if we descend to those still lower rays which are recognized only by their thermal effects. If we call the energy manifested in the solar beam by the general name of actinism, we may say that actinism is transformable into all the other modes of motion. In Mr. Grove's celebrated experiment, where a daguerreotype-plate is ingeniously connected with a galvanometer, a gridiron of silver wire, and a heat-registering helix, and where actinism is the initial mode of motion, there are obtained "chemical action on the plate, electricity in the wires, magnetism in the coil, heat in the helix, and [molar] motion in the needles."

In all cases where the disappearance of any given mode of motion is followed by the appearance of some other mode, the proof that there has been an actual transformation of the former mode into the latter is of two kinds. Deductive proof is furnished by the fact that the only alternative supposition is unthinkable,— namely, the supposition that the one kind of motion has been annihilated, while the other kind has been created for the occasion. Inductive proof is furnished by the fact that wherever it is possible to measure both the amount of motion that disappears and the amount that appears in its place, the two quantities are always found to be equal. Thus the molar motion implied in the fall of 772 pounds of matter through one foot of space will always raise the temperature of a pound of water just one degree of Fahrenheit. And similar quantitative correlations have been established among other modes of motion.

The second corollary from the persistence of force asserts that the direction of motion in any case is always the resultant between the lines representing respectively the greatest traction and the least resistance exerted by the forces upon which the motion depends. In any plexus of forces whatever, the resultant of all the tractive forces involved will be the line of greatest traction; the resultant of all the resisting forces will be the line of least resistance; and the direction of motion in the resultant of this final pair of resultants follows directly from the persistence of force. For the last resultant represents the direction and amount of a surplus force which remains after all the other forces have been equilibrated; and to assert that this force will not be manifested in motion along this line is to assert that force may be expended without effect. Still more obvious does this become, when we remember that "our only evidence of excess of force is the movement it produces." Since we know force not in itself, but only as revealed to consciousness in matter and motion, it follows that motion in any direction is the only proof we have that there is a surplus of unantagonized force acting in that direction. So that our theorem becomes almost an identical proposition. But if we ask *why* the greater of two opposing forces is that which causes motion in its own direction, there can be no answer save the one already given. There is no warrant save the consciousness that the unneutralized surplus of force cannot cease to act.

The simplest case contemplated by this corollary is that of a moving body left to itself. There being here no force involved, save the body's own momentum, the direction of motion is an infinite straight line. But since the realization of such a case would involve the annihilation of all matter save the body in question, it is obvious that no such simple case can ever have existed within the limits of the knowable universe. The simplest case of motion which can come within our cognizance is really complex to a degree which baffles computation. Mr. Spencer somewhere remarks that when a man appears to be walking westward, he is really being carried eastward by the earth's rotation at the rate of 1000 miles an hour. Besides this, the earth's orbital motion is carrying him westward at the differential rate of 67,000 miles an hour. Meanwhile the motion of the solar system toward the constellation Hercules is all the time bearing him in a direction neither east nor west. While, if we could comprehend in a single view the dynamic relations of the entire sidereal universe, we should find that even the enormous factors already taken into the account would help us but little toward determining the resultant direction in which the man is moving. The comparative ease with which astronomy ascertains the direction of the motions with which it deals is due to our ability to isolate ourselves theoretically from an indefinitely extended universe of environing bodies; and this is due to the principle, established by Galileo, that the relative motions of the parts of an aggregate are not affected by the motion of the whole. If we could include in the problem the entire knowable universe, we should doubtless find the real motions of a planet as impossible to calculate mathematically as are now the motions of a corpuscle of nerve-substance when thrown out of equilibrium by an act of thinking.

Nevertheless because of this principle that the relative motions of parts may be calculated independently of the motion of the whole, we are enabled legitimately to restrict our views, so that motion along the resultant of two or three forces may be determined and predicted with a near approach to accuracy. Witness the ease with which we can calculate the orbit of a comet. But when the forces become more numerous, it becomes impossible to determine their resultant. Witness the excessive difficulty of predicting the direction of currents in the atmosphere. The movements of organisms still more hopelessly baffle our powers of calculation. It is hardly probable that science will ever obtain equations for the motions of a lion in securing his prey; yet that would be a very shallow philosophy which should seek to assure us that each one of those motions does not take place along the resultant of all the forces involved. To an intelligence sufficiently vast, the motions of the earth in space would doubtless seem as complicated as those of the lion seem to us. But no amount of complexity can alter the fundamental principle that the direction of motion must be the resultant between the lines of greatest traction and of least resistance.

In conclusion let us observe that in many cases the total amount of traction is so small compared to the total amount of resistance, that for practical purposes it may be neglected; and *vice versa*. Thus, when a meteor falls upon the earth, we may neglect the resistance of the atmosphere, and say that the meteor follows the line of greatest traction; and when a volcano throws up a column of lava, we may neglect the effects of gravity, and say that for the time being the lava follows the line of least resistance. We shall thus, without any considerable inaccuracy, avoid cumbrous verbiage; and in the case of molecular motions propagated through masses of matter, with which our exposition is chiefly concerned, it is sufficiently accurate to say that motion follows the line of least resistance.

## CHAPTER II

## RHYTHM

THE third corollary from the persistence of force may best be introduced by a reconsideration of the simplest case of motion contemplated by the preceding corollary. The realization of Galileo's first law of motion — the law that a moving body must forever continue in a straight line with uniform velocity — obviously postulates the non-existence of any other matter than that contained in the body in question. If there were but one body in the universe, that body, when once set in motion, would never alter its direction, or undergo any increase or diminution of velocity. The introduction of a second body, attracting the first and attracted by it, alters the result in a way which now demands brief consideration. If the motion with which the two bodies start is such as would carry them along a straight line toward each other, they must obviously rush together, and the case is thus again reduced to that of a single moving body. But this case is too simple to have been ever actually realized. What we have to deal with is the case of two bodies which are moving in independent directions. For the sake of simplicity, let us suppose that the second body, B, is so much heavier than the first body, A, that the common centre of gravity of the two lies within B's periphery. What now will be the result? The *direction* of A's motion, instead of remaining unaltered, will be at each instant deflected from a straight line in such a way that A will continually approach nearer and nearer to a point somewhere in advance of B, upon the line in which B is moving: instead of a straight line we shall have a curve of which the coördinates will bear to each other a ratio equal to the ratio between A's momentum and B's tractive force. The *velocity* of A will also cease to be uniform. For as soon as A has passed on beyond B, a portion of its momentum will be at each instant consumed in neutralizing B's tractive force, so that the velocity due to the remaining momentum will be at each instant diminished. Now, unless A's momentum be infinite, this process cannot go on forever. By the time that A has arrived at the point directly in advance of B, so much momentum will have been lost that B's attraction will begin to overbalance it, and the curve in which A is moving will begin to turn back toward B. But now B's tractive force begins to augment at each instant the velocity of A, until, by the time that A has reached a position alongside of B, its momentum is considerably in excess of B's attraction, and it is consequently carried on toward a point in the rear of B. The same rhythmical decrease and increase in A's momentum continues until the curve is completed, and A has reached the position from which it started. Thus our attracted body, instead of moving in a straight line, moves in a closed curve of which one of the foci must coincide in position with the common centre of gravity of the attracted and attracting bodies. The result which we have here obtained by supposing A to be so much smaller than B that its reciprocal influence upon B's motion might be left unconsidered is not altered if we suppose A and B to be equal in size. In this case the common centre of gravity lies midway between the two bodies, and is the common focus of the two closed curves respectively described by them.

The illustration is a very trite one, being approximately realized in every case of planetary revolution, but the space here given to it is justified by the supreme importance of the principle now to be generalized from it. To Galileo's first law of motion there is now to be added a supplemental law. As a single moving body, in an otherwise empty universe, would move forever with unvarying velocity in an unvarying direction; so, on the other hand, two or more bodies, moving in independent directions and exerting attractive forces upon each other, must forever move in directions which rhythmically vary, and with velocities which are rhythmically augmented and diminished. Thus the rhythm of motion is a corollary from the persistence of force. Our only alternatives are rhythm, or invariable velocity in an invariable direction. The latter alternative being excluded by the fact that in the known universe innumerable bodies coexist, it follows that we must adopt the former, and admit that all motion is and must be rhythmical.

The direct dependence of this conclusion upon the axiom of the persistence of force is still further illustrated by the case of the pendulum. Let us imagine, for the sake of definiteness, a heavy bob at the end of a rigid wire. When the bob is raised to leftward of the perpendicular, and then left to the action of gravity, it at once begins to descend. But while it is descending, gravity is at each instant adding to its momentum, so that, when it reaches the perpendicular, it cannot stop, but is carried along to rightward until all the added momentum is lost again; that is, until it has ascended to a height equal to that from which it began to descend. Being now left to the unhindered action of gravity, the same series of motions will occur in the reverse direction, and so on forever.

Strictly speaking, no such case can be realized; since all the lost momentum is not expended in neutralizing gravity, but part of it is employed in communicating motion to the environing atmosphere, and part of it is transformed into heat. But if all the molar momentum thus dissipated could be retained, the rhythmic motion of the pendulum would continue forever. But why? Simply because the momentum acquired during the descending rhythm cannot cease to manifest itself, save as it is neutralized during the ascending rhythm. And to adduce this reason is to appeal directly to the persistence of force.

The case of undulatory motions propagated among the molecules of matter is precisely similar. The passage of an undulation implies at each instant a momentary local rarefaction, followed by a momentary local condensation. At a given instant certain molecules are removed farther from each other, while at the next succeeding instant they approach each other, and the molecules immediately adjacent are removed from each other. Why is rarefaction thus succeeded by condensation? What is it that determines the rebound of the disturbed molecule towards its original position? Obviously the progress of a pair of molecules toward positions farther and farther from each other is opposed by the inertia of adjacent molecules, which these push before them as they advance. The local rarefaction is achieved only at the expense of an adjacent condensation. This condensation of the adjacent molecules increases their elasticity until it begins to overbalance the momentum of the separating pair of molecules, and then these molecules are driven back toward each other. And so on, without intermission. Now the recoil of the advancing molecule is necessitated by the fact that the elasticity which it generates in the resisting molecule cannot expend itself without producing motion. And to say this is to recur again to our fundamental axiom.

Thus in all cases, whether molar or molecular, the rhythm of motion is necessitated by the fact that in a multiform universe no portion of matter can move uninfluenced by some other portion. The illustrations just given do but typify that which is forever going on throughout the length and breadth of the Cosmos. Periodicity, rise and fall, recurrence of maxima and minima, — this is the law of all motions whatever, whether exemplified by the star rushing through space, by the leaf that quivers in the breeze, by the stream of blood that courses through the arteries, or by the atom of oxygen that oscillates in harmony with its companion atoms of hydrogen in the raindrop. Always, as in our initial illustration, the forces which are carrying a given portion of matter in a given direction become gradually altered in their distribution, and in their amounts, until the direction of the motion becomes practically reversed; and whether the given portion of matter be a planet or a molecule, the dynamic principle remains the same. Just as Newton's law of inverse squares applies to molecules as well as to masses, so the law of rhythm applies in both cases. Thus what we may call the elementary motions going on throughout the world of phenomena — the elementary motions by the various combinations of which all perceptible motions are made up — are all rhythmical or oscillatory. The phenomena which are presented to our consciousness as light, heat, electricity, and magnetism, are the products of a perpetual trembling, or swaying to and fro of the invisible atoms of which visible bodies are composed. When we contemplate the heavens on a clear autumn evening, and marvel at the beauty of Sirius, that beauty is conveyed to our senses through the medium of atomic shivers, kept up during the past twenty-two years, at the average rate of six hundred millions of millions per second. The difference between the tropical heat of India and the cold of the Arctic regions is simply the measure of untold millions of tiny differences in the rates of oscillation of countless atoms of atmospheric gases, determined in turn by innumerable oscillatory movements propagated from the sun to the earth. The difference between the faradaic current which cures some deep-seated abnormity of nutrition, and the lightning-flash which paralyzes and kills, is at bottom a difference in amounts and rates of atomic vibration. And according to the latest speculations in chemical philosophy, it is because of the synchronousness or rhythmical harmony of the oscillatory movements described by their atoms, that elementary substances are enabled to combine in myriadfold ways, thus making up the wondrous variety of forms, organic and inorganic, which the earth's surface presents for our contemplation.

Since the ultimate particles of which science regards the universe as composed are thus perpetually swaying to and fro, in accordance with a law of motion that admits of no exception, we may expect to find that the various aggregates of these particles which constitute perceptible bodies will exhibit a like rhythm, whether comparatively simple or endlessly compounded, in their motions. The law which governs the action of the parts must govern also the action of the whole, no matter how intricately the whole may be compounded. Whether it be in the case of organic or inorganic bodies, of complex or of simple aggregates, we must expect to come upon systems of rhythmical movements, which will be comparatively simple or endlessly complex, according to the structural complication of the bodies in question. Let us exhibit a few instances of this rhythmical action, before we pass to the stupendous consequences of the theorem which I have been endeavouring to elucidate. Some of the chief instances to be gathered from astronomic phenomena have been so admirably presented by Mr. Spencer, that I cannot do better than to quote in full his concise statement.

Along with the planetary revolutions which furnish the illustration with which I began this chapter, "the solar system presents us with various rhythms of a less manifest and more complex kind. In each planet and satellite there is the revolution of the nodes — a slow change in the position of the orbit-plane, which after completing itself commences afresh. There is the gradual alteration in the length of the axis major of the orbit, and also of its eccentricity, both of which are rhythmical alike in the sense that they alternate between maxima and minima, and in the sense that the progress from one extreme to the other is not uniform, but is made with fluctuating velocity. Then, too, there is the revolution of the line of apsides, which in course of time moves round the heavens — not regularly, but through complex oscillations. And further we have variations in the directions of the planetary axes — that known as nutation, and that larger gyration which, in the case of the earth, causes the precession of the equinoxes.

"These rhythms, already more or less compound, are compounded with each other. Such an instance as the secular acceleration and retardation of the moon, consequent on the varying eccentricity of the earth's orbit, is one of the simplest. Another, having more important consequences, results from the changing direction of the axes of rotation in planets whose orbits are decidedly eccentric. Every planet, during a certain long period, presents more of its northern than of its southern hemisphere to the sun at the time of its nearest approach to him; and then again, during a like period, presents more of its southern hemisphere than of its northern — a recurring coincidence which, though causing in some planets no sensible alterations of climate, involves in the case of the earth an epoch of 21,000 years, during which each hemisphere goes through a cycle of temperate seasons, and seasons that are extreme in their heat and cold. Nor is this all. There is even a variation of this variation. For the summers and winters of the whole earth become more or less strongly contrasted, as the eccentricity of its orbit increases and decreases. Hence during increase of the eccentricity, the epochs of moderately contrasted seasons and epochs of strongly contrasted seasons, through which alternately each hemisphere passes, must grow more and more different in the degrees of their contrast; and contrariwise during decrease of the eccentricity. So that in the quantity of light and heat which any portion of the earth receives from the sun, there goes on a quadruple rhythm: that of day and night; that of summer and winter; that due to the changing position of the axis at perihelion and aphelion, taking 21,000 years to complete; and that involved by the variation of the orbit's eccentricity, gone through in millions of years."[1]

The astronomic rhythms here enumerated are peculiarly interesting from the fact that, owing to their comparatively simple character, they are susceptible of mathematical treatment, so that their direct dependence on the principle of the persistence of force can be quantitatively demonstrated. In ascending to the order of phenomena next above them in point of complexity — the geologic phenomena occurring on the earth's surface — we enter a region where such quantitative proof, save of a very crude sort, cannot be obtained. The great complexity of geologic as contrasted with astronomic rhythms is shown by the fact that whereas on the one hand we can readily calculate the variations of eccentricity in the earth's orbit which

[1] *First Principles*, pp. 256, 257.

have taken place during millions of years gone by or which are sure to take place during millions of years to come, on the other hand we are not yet able to assign an approximate date for the most recent epoch at which our northern hemisphere was covered with glaciers. According to Mr. Wallace this epoch may have occurred no more than seventy thousand years ago, while others would assign to it an antiquity of at least two hundred thousand years, and there are yet others who urge strong arguments in behalf of the opinion that a million of years is barely enough to have produced the changes which have taken place since that event. Nevertheless, though we cannot determine the amounts and durations of the movements which have occurred during the geologic history of the earth, we can still securely assert that these movements have been rhythmical in character. Though the verdict is rendered with less precision, its purport is still the same. In the alternating periods of elevation and depression which have succeeded each other at different places ever since the earth's crust began to be solidified, are exemplified the chief geologic rhythms, due to the slow deflection of the lines of least resistance along which the pressure of the earth's nucleus reveals itself by causing upward motion. But these immensely long rhythms are complicated by minor rhythmical changes of surface, due to continual shifting of river-beds and consequent variations in the areas of denudation and in the deposit of sedimentary strata. And these rhythms are still further complicated by rhythmic variations in the operation of climatic agencies, entailing periodic changes in the amount and distribution of rainfall, in the size and movements of icebergs and glaciers, and in the activity of frost. On the seashore we may witness the compound rhythm of the tides, in "which the daily rise and fall undergo a fortnightly increase and decrease, due to the alternating coincidence and antagonism of the solar and lunar attractions;" a source from which arise the most minute geologic rhythms, as those which arise from the secular cooling of the earth, and from its ever varying position in space, are the most vast.

But the subject of complex rhythms is still better illustrated in biology. The commonest physiological act, such as eating, is dependent upon a periodically occurring sensation of hunger, due to a periodic excess of waste over repair. The taking of nutriment is accomplished, in all animals, by a series of rhythmical motions, — either the motions of cilia, or of sphincter muscles, or of jaws, or indeed of all three at once. Mr. Spencer adds that "the swallowing of food is effected by a wave of constriction passing along the œsophagus; its digestion is accompanied by a muscular action of the stomach that is also undulatory; and the peristaltic motion of the intestines is of like nature. The blood obtained from this food is propelled not in a uniform current but in pulses; and it is aerated by lungs that alternately contract and expand." To this we may add that assimilation is a continuous process of rhythmic interchange between the molecular constituents of the various tissues and of the blood by which they are bathed; that muscular action is the result of a series of oscillatory movements; and that nervous action depends upon a quickly alternating rise and fall in the chemical instability of the molecules which compose the nerve-centres. All these minor rhythms are as ripples upon the surface of the longer rhythm constituted by sleep and wakefulness. Recent researches have shown that sleep itself furnishes a beautiful illustration of the manner in which rhythm is necessitated by the continual redistribution of forces in the organism. According to the most recent view, sleep is caused by a diminution in the capacity of the cerebral arteries, which lessens the circulation of blood through the brain. It is the sympathetic nerve which effects this contraction of the arteries. During the day the activity of the cerebrum itself supplies the stimulus which causes arterial blood to flow through the head in large quantities, so as to keep the vessels duly distended. But after many hours of activity the ratio of repair to waste is sensibly diminished ; there is a fall in the average chemical instability of the cerebral nerve-molecules, and a consequent diminution in the amount of cerebral stimulus ; until presently the amount of stimulus sent up from moment to moment along the cervical branch of the sympathetic nerve exceeds the amount which the cerebrum can oppose to it. Experiment has shown that the effect of stimulating the sympathetic nerve is to contract the muscular walls of the cerebral arteries. The supply of arterial blood is thus so far diminished that consciousness ceases. But now the other half of the rhythm begins. The cessation of conscious activity greatly diminishes the waste of cerebral tissue — and, although repair is also somewhat lessened by the lessened blood-supply, yet the ratio of repair to waste is increased. The complex nerve-molecules are built up to higher and higher grades of instability, until it only needs a slight stimulus from without, in the shape of a sensation of sound or of light or of touch, to elicit a discharge of nerve-force from the cerebral ganglia. This discharge is instantly answered by a rush of blood, which distends the cerebral arteries, revives consciousness, and holds in abeyance the contractile energy of the sympathetic nerve, until the decreasing ratio of repair to waste by and by necessitates a recurrence of the rhythm. Thus the alternation of sleep and wakefulness is due to a periodic variation in the ratio between the amount of nerve-force stored up in the cerebrum and the amount stored up in the sympathetic ganglia. We recognize this truth in practice when we seek to induce sleep by stimulating the sympathetic nerve with such substances as bromide of potassium.

The phenomenon of sleep is still further interesting as the most familiar instance of the dependence of biologic rhythms upon astronomic rhythms. All organisms, animal and vegetable, from the highest to the lowest, exhibit alternations in the total distributions of their forces, which coincide with the periodic appearance and disappearance of sunlight. The longer astronomic rhythm, known as the earth's annual revolution, causes corresponding rhythms in vegetable and animal life; witness the blossoming and leafing of plants in the spring, the revival of insect activity at the same season, the periodic flights of migratory birds, the hibernating sleep of many vertebrates, and the thickened coats or the altered habits of others that do not hibernate. If we consider the species instead of the individual, we shall find that still longer astronomic rhythms, often complicated by geologic rhythms, cause periodic changes in the total manifestations of life upon the earth's surface. Recurring epochs of high eccentricity of the earth's orbit have so altered the distribution of solar radiance as to cause violent climatic vicissitudes. Large portions of the earth have been covered by glaciers, and there have been ensuing migrations of plants and animals, attended by the extinction of many forms, and by specific variations among the survivors. Other rhythms in the distribution of life have been caused by alternations in the elevation and subsidence of continents and islands. And all the foregoing causes, taken altogether, have been endlessly complicated by rhythmic changes in the relations of various groups of organisms to one another. The complexity of such relations is strikingly illustrated in an instance given by Mr. Darwin. The fertilization of heartsease and red clover is impossible without the agency of humble-bees in carrying the pollen from one flower to another. Other bees do not visit these flowers, as their probosces are not long enough to reach the nectar; while moths, which have sufficiently long probosces, are not heavy enough to bend down the petals in such a way that the anthers above may shed pollen upon their backs. Hence the partial or total destruction of humble-bees must involve the decrease or extinction of heartsease and red clover. But observation shows that the mortal foes of humble-bees are field-mice, who destroy their combs and nests. It is estimated that in England more than two thirds of each generation of humble-bees are destroyed by mice. Hence it follows that the cat is a friend and protector of the humble-bee; and that any sensible variation in the number of cats in a given district must indirectly cause a variation in the numbers of heartsease and red clover which grow in the neighbourhood. It is only needful to add that in such variations we have a series of endlessly complex rhythms; as is obvious from the fact that the number of individuals in any species is never constant, but is continually fluctuating about an average mean. The cumulative result of such rhythms, going on through countless ages, is witnessed in the rhythmical changes of organic species revealed by palæontology. In all ages species have been encroaching on each other, and while some have been growing more abundant, others have gradually disappeared. Thus we find successive floras and faunas, characteristic of successive geological epochs, showing that "life on the earth has not progressed uniformly, but in immense undulations."

For the further illustration and more abundant proof of the law that all motion is rhythmical, I must refer to Mr. Spencer's "First Principles," where the subject is discussed much more fully than is here practicable. But our last illustration, from the succession of forms of life upon the earth, suggests still another supremely important aspect in which the general principle must be viewed, before we leave it.

As we saw in our initial illustration, from the movements of heavenly bodies, where a rhythmical motion is dependent on only two compounded forces, the result is a closed curve. Though each planet is, strictly speaking, subjected to a great number of variously compounded forces exerted on it by all its companion planets, yet these forces are so insignificant in quantity, compared to the two chief forces of solar gravity and the planet's own momentum, that they do not essentially alter the result. They prevent the curve in which any given planet moves from being perfectly regular, but they do not prevent its being a closed curve so far as the solar system alone is concerned; so that, at the end of each rhythm, the distribution of forces is very nearly the same as at its beginning. If there were only two bodies concerned, it would be exactly the same: every rhythm would end in bringing about precisely the same state of things with which it started. But where there are a vast number of forces at work, as in the evolution of the earth and of life upon its surface, the probability is infinitely small that any pair of forces can so far predominate over all the rest as to reduce their effects to comparative insignificance. Hence the resulting rhythms will not be closed curves, but endlessly complicated undulations; and every rhythm will end in bringing about a state of things somewhat different from that in which it started. To recur to some of the illustrations above given: No geologic rhythm of elevation and subsidence leaves the distribution of land and water over the earth exactly as it found it. No biologic rhythm of sleep and wakefulness leaves the distribution of nutritive forces in the organism precisely as it found it; otherwise it would not be true that each day's functional activity is a member of the series of changes which is bearing us from the cradle to the grave. In an exogenous tree each annual rhythm results in a permanent increase of woody fibre: in a mammal it results in at least a relative increase of the solid constituents of the body as compared with the fluid and semifluid constituents. And our illustration from palæontology shows that the series of enormous rhythms in which the history of organic life consists, has introduced a new state of things in each geologic epoch.[1]

We have now proceeded as far as a survey

[1] Hence the theory of Vico, that social progress takes place in cycles in which history literally repeats itself, is based upon a very inadequate knowledge of the results of the coöperation of many interacting forces.

of the widest generalizations of physics can carry us, and before we attempt to go further, we may fitly present in a single view the conclusions reached in this and in the preceding chapter.

We observed first that the three departments of abstract-concrete science are alike concerned with the investigation of the general laws of force as manifested in the motions of matter. By an analysis of the widest propositions which these sciences can furnish, concerning the movements of masses and molecules, we arrived at the axiom that every manifestation of force must be preceded and followed by an equivalent manifestation. We saw that this axiom is involved, alike in every special theorem with which each physical inquiry sets out, and in the general theorem of the uniformity of law and the universality of causation with which all physical inquiries must equally set out. We saw next that this axiom gives rise to three corollaries which, as expressing truths that transcend the sphere of any single science, belong to that transcendental region of knowledge which we have assigned to philosophy. By our first corollary it appeared that any given mode of motion may be metamorphosed into several other modes; so that, when we contemplate such a complex system of motions as that presented by the various aggregations of matter upon the surface of our earth, it becomes legitimate to inquire from what antecedent form of energy proceeded all these motions. This inquiry we shall make in due season. By our second corollary it appeared that where motion results from the composition of two or more forces, it must always take place in the line of least resistance; but that the difficulty of calculating or predicting this resultant line must increase very rapidly with each addition to the number of forces which are concerned in producing it.

Our third corollary has given us glimpses of a truth, which, though less immediately obvious, is equally necessary and equally important with any of the foregoing. We have seen that, in the hypothetical case of a single moving body in an otherwise empty universe, the direction of motion would be in a straight line, and the velocity would be uniform. In the hypothetical case of a single pair of mutually attracting bodies moving in independent directions in an otherwise empty universe, the motion would be rhythmical both in direction and in velocity, but it would take place in closed curves, and the distribution of forces at the end of each rhythm would be the same as at the beginning. In the simplest of actual cases, however, — in the case of our planetary system, — such a result, though apparently realized so long as we eliminate from the problem all factors save the two principal ones, is not truly realized; and if we were to take into account the motions of the whole system, due to the forces exerted upon it by remote stellar systems, we should see that it is very far from being realized. Viewed in its relations to the entire visible universe of stellar bodies, no planet moves in a closed curve; and if we also take into consideration the unceasing loss of molecular motion by each cosmical body, we shall perceive that even in this relatively simple class of cases, the rhythms are far too complex ever to result in the reproduction of a given distribution of forces. In the relatively complex cases furnished by geology and biology, this truth is still more strikingly exemplified. Thus in the actual case with which our science has to deal — the case of a universe in which innumerable millions of bodies, from a gigantic star like Sirius down to an inconceivably minute atom of hydrogen, are ceaselessly exerting forces upon each other — we see, not only that all motions must be rhythmical, but that every rhythm, great or small, must end in some redistribution, be it general or local, of matter and motion.

Or to state this final conclusion in a slightly different form, — the mere coexistence of a vast number of bodies in the universe necessitates perpetual rhythm, resulting in a continuous redistribution of matter and motion. Thus fresh significance is given to the truth vaguely surmised by Herakleitos, that ceaseless change is the law of all things, and that the universe of phenomena is in a never-ending flux. But the scientific demonstration further shows us that the change is always from an old state to a new state, and thence to another new state, but never back to the old state. Among the untold millions of forces which science contemplates as coöperating to bring about any given state of things, the permutations and combinations are practically infinite; and not until they have all been exhausted can an expired epoch be reproduced in all its features.

## CHAPTER III

# EVOLUTION AND DISSOLUTION

WE must now consider what use is to be made of these universal truths which the foregoing survey of the abstract-concrete sciences has disclosed. For if we inquire whether these theorems, singly or combined, can be made to supply the materials needful for constructing such an organized body of truths as may fitly be called Cosmic Philosophy, it will require but a brief consideration to show us that much more is needed.

In respect of universality, no doubt, these truths leave nothing to be desired. That every manifestation of force must be preceded and followed by an equivalent manifestation; that correlated forms of energy are transmutable one into the other; that motion follows the line of least resistance; and that there is a continuous rhythmical redistribution of matter and motion; — these are propositions which are true alike of all orders of phenomena, and may therefore justly claim to be regarded, in a certain sense, as philosophic truths. Yet we need only fancy ourselves enunciating these abstract theorems as of themselves supplying the explanation of any given order of concrete phenomena, in order to realize how far we still remain from our desired goal. If we were to remind a biologist that in every step of his investigations he takes for granted the persistence of force, he would doubtless assent; but if we were to go on and assert that upon this axiom might be directly reared a science of organic phenomena, he would laugh us to scorn. If we were to assure him that every form of energy manifested by his organisms, from the molar motions of the stomach in digestion and the lungs in respiration to the molecular motions of cerebral ganglia, must have preëxisted in some other form, he would thoroughly agree with us, but would ask us of what use is all this unless we can trace the course and the results of the transformations. If we were still to insist that all the motions taking place in the aforesaid organisms occur rhythmically, along lines of least resistance, and that every such rhythm ends in a more or less considerable redistribution of molecular motions, we might still be met by the answer that all this does not give us a science of biology unless we can also point out the general character and direction of the changes in which organic rhythms result.

In other words, our biologist might say to us, with Mr. Spencer, that all these profound truths, with which we were seeking to take away his occupation, are *analytical* truths, and that "no number of analytical truths will make up that synthesis of thought which alone can be an interpretation of the synthesis of things. The decomposition of phenomena into their elements" (he would continue) "is but a preparation for understanding phenomena in their state of composition, as actually manifested. To have ascertained the laws of the factors is not at all to have ascertained the laws of their coöperation. The question is, not how any factor behaves by itself, or under some imagined simple conditions; nor is it even how one factor behaves under the complicated conditions of actual existence. The thing to be expressed is the joint product of the factors under all its various aspects. Only when we can formulate the total process, have we gained that knowledge of it which Philosophy aspires to."[1]

It is necessary for us therefore, having finished our analysis, to begin the work of synthesis. In the course of our search for the widest generalizations of Physics, we discovered, as the most concrete result of analysis, that there is going on throughout the known universe *a continuous redistribution of matter and motion.* Let us now, following out the hint of our imaginary interlocutor, endeavour to ascertain the

[1] *First Principles*, p. 274.

extent, character, and direction of this continuous redistribution. Have the infinitude of changes in the aspect of things, which the rhythm of motion necessitates, any common character, and if they have, what is that character? Are the redistributions of matter and motion, which are going on all around us, aimless and unrelated, or do they tend in common toward some definable result? Can any formula be found which will express some dynamic principle, true of the whole endless metamorphosis?

Or, to state the case in a still more concrete form, when we assert "that knowledge is limited to the phenomenal, we have by implication asserted that the sphere of knowledge is coextensive with the phenomenal. Hence wherever we now find Being so conditioned as to act on our senses, there arise the questions — how came it thus conditioned? and how will it cease to be thus conditioned? Unless on the assumption that it acquired a sensible form at the moment of perception, and lost its sensible form the moment after perception, it must have had an antecedent existence under this sensible form, and will have a subsequent existence under this sensible form. These preceding and succeeding existences under sensible forms are possible subjects of knowledge; and knowledge has obviously not reached its limits until it has united the past, present, and future histories into a whole."[1]

Let us not fail to note that science and ordinary knowledge concern themselves with such problems no less than philosophy; and that in seeking to formulate the past, present, and future history of that aggregate of sensible phenomena which constitutes the knowable universe, philosophy transcends the sphere of science in just the same way that science transcends the sphere of ordinary knowledge, and in no other. A large portion of that imperfectly organized knowledge that serves to guide the actions even of the least educated men, consists of information concerning the past and future careers of the objects which surround them. Thus we recognize the child of twenty years ago in the grown man of to-day; we know that the coat which the man wears recently existed in the shape of unspun and unwoven wool upon a sheep's back; and that the grass upon which this sheep fed consisted of matter integrated by countless seeds with the aid of solar radiance. And we know, besides, that the man and the coat which he wears, the sheep and the grass upon which it feeds, must alike pass from their present state of aggregation into a future state of dissolution. This kind of knowledge science is ever extending, as when it traces back the man and the

[1] *First Principles*, p. 278.

sheep to microscopic germ-cells, and the wool and the grass to certain nitrogenous and hydrocarbon compounds, preëxisting in the atmosphere and soil. Obviously, therefore, it is the business of philosophy, extending and generalizing the same kind of information, to describe the universal features of the process by which cognizable objects acquire and lose the sensible forms under which we know them.

By pointing out the two most obvious features of this process, we shall render still more intelligible the character of the problem which a synthetic philosophy must attempt to solve. The foregoing illustrations show us that a complete account of anything "must include its appearance out of the imperceptible, and its disappearance into the imperceptible." Now a change of state by virtue of which any object ceases to be imperceptible and becomes perceptible must be a change from a state of diffusion to a state of aggregation, — and the converse change, from aggregation to diffusion, must be the change by virtue of which the object again becomes imperceptible. If, for example, we study a cloud, we find that a complete history of it is contained in the explanation of its concentration from millions of particles of aqueous vapour, and its subsequent dissipation into a host of such particles. In like manner, if we study an organism, we find that from germination to final decomposition, its career consists of an epoch of concentration followed by an epoch of diffusion. A very small portion of its constituent matter preëxisted in a concentrated form in the embryo; by far the greater portion preëxisted in the shape of dispersed nitrogenous and carbonaceous compounds, which the growing organism has incorporated with its own structure. Nay, even if we inquire into the previous history of the small portion which was concentrated in the embryo, we may trace it back to an epoch at which it existed in a state of dispersion, as food not yet assimilated by the parent organism. If the organism in question belong to an order of carnivorous animals, we shall indeed have to follow its constituent elements through a series of phases of concentration; through the tissues of sundry herbivorous animals upon which it has fed, and again through the tissues of numerous plants upon which these have in turn subsisted; but in the end we shall always arrive at the host of dispersed molecules which these organisms have eliminated from the breezes and the trickling streamlets by which their leaves and roots were formerly bathed. On the other hand, when the animal dies, and the tree falls to decay, the particles of which they consist are again dispersed; and though they may again be brought together in new combinations, the career of the organism in question is ended with this dispersal. Again if, instead of a transient cloud or a mobile organism, we contemplate an apparently permanent and immobile rock, we are led to a like conclusion. If its origin be purely igneous, this rock may have preëxisted as a liquid stream of matter surging beneath the earth's solid envelope. If its origin be aqueous, its constituent particles were once diffused over a wide area of country, from which they were drawn together through sundry rivulets and rivers, and here at last deposited as sediment. In either case the process by which the rock has assumed an individual existence has been a process of concentration. And when it ceases to exist — whether it is blasted with gunpowder, or chipped away with chisels, or eaten down by running water, or ground to pieces by ocean waves, or lowered through some long geologic epoch till it is melted by volcanic heat — in any case its disappearance is effected by a process of diffusion.

But our account is as yet only half complete. In saying that the career of any object, from its initial appearance to its final disappearance, consists of a process of concentration followed by a process of diffusion, we omit an important half of the truth. For in making such a statement, we are attending only to the material elements of which objects are composed; and we are leaving out of the account the motions, both molar and molecular, which they exhibit, and which constitute an equally important part of the entire process. This defect we must now endeavour to remedy.

A brief reconsideration of the examples already cited will show us that universally the concentration of matter is accompanied by a dissipation of motion, while conversely the diffusion of matter is attended by an absorption of motion. The condensation of aqueous vapour into a cloud is effected whenever it loses by radiation a greater quantity of that kind of molecular motion known as heat than it is receiving from the sun and the earth; and when the loss of motion is still more considerable, there occurs a further condensation of the aqueous vapour into liquid rain. Conversely, when solar radiance, direct or reflected, begins to impart to the condensing cloud an amount of molecular motion in excess of that which it loses from moment to moment, condensation ceases, and the particles of vapour begin to be dissipated. The deposit of sediment at the mouth of a river is attended by the loss of the molar motions which brought its constituent particles from the upland regions which the river drains; and the hardening of the sediment into rock is a change to a state of aggregation in which, along with greater cohesion, the particles possess less mobility than before. In like manner the hardening of an igneous rock is effected by cooling, which implies the loss of internal motion. Indeed the phenomena of heat and cold exhibit *en masse* an illustration of the general principle. The progress of any mass of matter from a gaseous to a liquid, and thence to a solid state, is attended by the continuous dissipation of molecular motion; while change in the contrary direction is attended by a continuous absorption of such motion. With molar motions the case is precisely similar. "Augment the velocities of the planets, and their orbits will enlarge; the solar system will occupy a wider space. Diminish their velocities, and their orbits will lessen; the solar system will contract. And in like manner we see that every sensible motion on the earth's surface involves a partial disintegration of the moving body from the earth, while the loss of its motion is accompanied by the body's reintegration with the earth." Finally, if we consider the case of organisms, we find that the incorporation of food into the substance of the tissues is constantly accompanied by the giving out of motion in some form of organic activity, while conversely, the decomposition which follows death is attended by an immense absorption of molecular motion. The latter statement is proved by the fact that the elements of which such an organism as the human body is composed have more than twenty times the volume when free which they have when combined; and it is further illustrated by the fact that dead organisms, from which all supply of molecular motion from without is artificially cut off, are not decomposed. It is thus that animal remains are preserved for ages in blown sand and in peat-moss. And it is thus that the carcases of primeval mammoths, intact even to the bulbs of the eyes, are found embedded in arctic ice near the mouths of Siberian rivers, just where they were slain by the cold a thousand centuries ago.[1]

But the study of organic phenomena shows us that our general theorem needs some further revision. As it now stands, it runs some risk of being supposed to assert that the career of any composite body is at first characterized solely by the concentration of matter and concomitant dissipation of motion, and is at last characterized solely by the diffusion of matter and concomitant absorption of motion. A reference to the history of any organism will at once show that this is not the case. While the human body, for example, is continually incorporating with its tissues new matter in the shape of prepared food, large portions of the matter once incorporated are continually diffused in the

[1] The heads of these animals are nearly always directed *southward*. See Lyell, *Principles of Geology*, 10th edition, vol. i. p. 184.

shape of excretions through the lungs, liver, skin, and kidneys. And while it is constantly parting with motion, in the shape of radiated heat, of expended nerve-force, and of molar motion communicated to the surrounding objects which it touches or handles, it is at the same time absorbing large quantities of molecular motion latent in its prepared nutriment. But at no time are the antagonist processes exactly balanced. During early life the excess of concentration over diffusion of matter results in growth. At a later date the rhythms due to the alternate predominance of concentration and diffusion are exhibited in continual fluctuations in weight. Yet the fact that the healthy body usually increases in weight up to a late period shows that ordinarily concentration is still predominant. And this is still more convincingly proved by the fact that in old age, when the body frequently decreases both in weight and in volume, the weight decreases less than the volume. There is a general increase in density, and concomitant loss of mobility, due to the increased ratio of the solid to the fluid constituents of the tissues, and exhibited in the hardness and brittleness of the bones, the stiffness of the joints, the sluggishness of the circulation, and the torpidity of the brain. Finally when, in accordance with the general principle of rhythm, the consolidation has gone so far as to become self-defeating, the antagonist process gains the mastery for which it has all along been striving, and the constituents of the body are separated and scattered.

But the coexistence and alternate mastery of these two opposing processes, though most strikingly exemplified in the case of organisms, is by no means confined to organic phenomena. Neither in the cloud, nor in the rock, which we have chosen as examples, does concentration or diffusion ever go on alone. The one is always antagonized by the other. Even while the cloud is most rapidly losing motion and integrating matter, it is receiving some solar radiance, either direct or reflected from the earth or moon, and the absorption of this radiance causes some disintegration of its matter. Even while it is most quickly vanishing under the burning solar rays, this cloud is still simultaneously losing heat by radiation, and the loss tends to reintegrate it. And likewise our sedimentary rocky deposit, while aggregating, is nevertheless daily abraded by passing currents, and at longer intervals is perhaps cracked by those telluric vibrations known as earthquakes.

As finally amended then, our formula asserts that the career of any composite body is a series of more or less complicated rhythms, of which the differential result is, *at first*, the integration of its constituent matter and the dissipation of part of its contained motion, and, *at last*, the diffusion of its constituent matter accompanied by reabsorption of the lost motion, or its equivalent.

Thus we are gradually reaching something like a concrete result. As we saw, in the preceding chapter, that rhythm necessitates a continual redistribution of matter and motion throughout the knowable universe, we now find that this continual redistribution everywhere results in alternate concentration and diffusion. Such, indeed, must inevitably be the result. The same universal principle of dynamics which prevents the perturbations in the solar system from ever accumulating all in the same direction is also to be seen exemplified, on a more general scale, in the law that neither aggregation nor diffusion can proceed indefinitely without being checked by the counter-process. Unless we suppose that the sum of the forces which produce aggregation is infinitely greater or infinitely less than the sum of the forces which resist aggregation, so that either the one or the other may be left out of the account, we must admit that the only possible outcome of the conflict between the two is a series of alternations, both general and local, between aggregation and dissipation.

It is now the time to apply to these antagonist processes some more convenient and accurate names than the half-dozen pairs of correlative synonyms by which we have thus far described them. The names selected by Mr. Spencer will be practically justified by the entire exposition contained in the following chapters; but even the cases already fragmentarily studied enable us partly to realize the significance of the terms Evolution and Dissolution, by which he has designated these processes. In Mr. Spencer's terminology, the integration of matter and concomitant dissipation of motion is Evolution — while the absorption of motion and concomitant disintegration of matter is Dissolution. Both these terms possess the signal advantage that, while they admit of precise scientific definition, they are at the same time currently used in senses strictly analogous to those in which they are here employed. As we shall presently see, the phenomena of organic life are those in which both the primary and the secondary characteristics of Evolution and Dissolution are most conspicuously exemplified. Especially in the career of the animal organism, these complementary processes are manifested in groups of phenomena that are more easily generalized and more immediately interesting than any others of like complexity; and to these groups of phenomena the terms Evolution and Dissolution have long been popularly applied.

On a superficial view it may now seem as if we were ready to proceed, in the next chapter, to describe in detail the process of Evolution, as exemplified in that most gigantic instance of concentration of matter and dissipation of motion, — the development of our planetary system, by condensation and radiation, from ancestral nebulous matter. In this origin, by aggregation, of our system of worlds, and in that ultimate dissipation of it into nebulous matter which sundry astronomic facts have long taught us to anticipate, we shall presently find a complete and striking illustration of the dynamic principles herein set forth. But we are not yet quite prepared to enter upon the consideration of these phenomena. We need but remember that in the development of the solar system, with its mutually dependent members sustaining complex and definite relations to each other, much more is implied besides concentration of planetary matter and diffusion of molecular motion in the shape of heat; we need but remember this, and we shall see that some further preliminary study is requisite. While, indeed, the primary characteristics of Evolution and Dissolution are those which are expressed in the pair of definitions above given, and which it has been the object of the foregoing inquiry to illustrate; there are also, as just hinted, certain secondary characteristics which it is equally necessary to formulate. While Evolution always consists primarily in an integration of matter and concomitant dissipation of motion, it ordinarily implies much more than this. And it is obvious that only when all the characteristics, both primary and secondary, of Evolution and Dissolution, are expressed in a single formula, can we be said to have obtained the law of the continuous redistribution of matter and motion which rhythm necessitates throughout the knowable universe.

To show how this, the most sublime achievement of modern science, has been brought about, will be the object of the following chapter.

## CHAPTER IV

# THE LAW OF EVOLUTION

LAPLACE has somewhere reminded us that, while gratefully rendering to Newton the homage due to him for his transcendent achievements, we must not forget how singularly fortunate he was in this — that there was but one law of gravitation to be discovered. The implication that, if Newton had not lived, Laplace might himself have been the happy discoverer is perhaps a legitimate one, though it does not now especially concern us. But the implied assertion that Nature had no more hidden treasures comparable in worth and beauty to that with which she rewarded the patient sagacity of the great astronomer is one which recent events have most signally refuted. We now know that other laws remained behind — as yet others still remain — unrevealed; laws of nature equalling the law of gravitation in universality, and moreover quite as coy of detection. For while it may be admitted that the demonstrations in the "Principia" required the highest power of quantitative reasoning yet manifested by the human mind; and while the difficulties and discouragements amid which Newton approached his task, destitute as he was alike of modern methods of measurement and of the resources of modern analysis, impress upon us still more forcibly the wonderful character of the achievement; it must still be claimed that the successful coördination of the myriad-fold phenomena formulated by the Law of Evolution was a gigantic task, requiring the full exertion of mental powers no less extraordinary than those required by the other. In an essay published thirteen years ago, youthful enthusiasm led me to speak of Mr. Spencer's labours as comparable to those of Newton both in scope and in importance. More mature reflection has confirmed this view, and suggests a further comparison between the mental qualities of the two thinkers; resembling each other as they do, alike in the audacity of speculation which propounds far-reaching hypotheses and in the scientific soberness which patiently verifies them; while the astonishing mathematical genius peculiar to the one is paralleled by the equally unique power of psychologic analysis displayed by the other. As in grandeur of conception and relative thoroughness of elaboration, so also in the vastness of its consequences — in the extent of the revolution which it is destined to effect in men's modes of thinking, and in their views of the universe — Mr. Spencer's discovery is on a par with Newton's. Indeed, by the time this treatise is concluded, we may perhaps see reasons for regarding it as, in the latter respect, the superior of the two.

To give anything like an adequate idea of the extent and importance of this discovery, or of the enormous mass of inductive evidence which joins with deduction in establishing it, is of course impracticable within the limits of a single chapter. We must be content for the present with exhibiting a rude outline-sketch of its most conspicuous features, leaving it for the succeeding series of discussions to finish the picture. Let us begin by briefly summing up the results already obtained.

It has been shown that the coexistence of antagonist forces throughout the knowable universe necessitates a universal rhythm of motion; and that in proportion to the number of forces anywhere concerned in producing a given set of motions, the resulting rhythms are complex. It has been further shown that, save where the rhythms are absolutely simple — a case which is never actually realized — there must occur a redistribution of matter and motion as the result of each rhythm. It next appeared that such a redistribution involves on the one hand an integration of matter, which implies a concomitant dissipation of motion, and on the other hand a disintegration of matter, which implies a concomitant absorption of motion. The former process, which results in the acquirement of an individual existence by sensible objects, has been named Evolution — the latter process, which results in the loss of individual existence by sensible objects, has been named Dissolution. And we saw it to be a corollary from the universality of rhythm that, while these two antagonist processes must ever be going on simultaneously, there must be an alternation of epochs during which now the former and now the latter is predominant. In conclusion, it was barely hinted that these two fundamental modes of redistribution must give rise, in the majority of cases, to secondary redistributions, which it is the business of a scientific philosophy to define and formulate.

Now, as we are about to start upon a long and complicated inquiry, the proper treatment of which must task our utmost resources of exposition, it will be desirable at the outset to disencumber ourselves of all such luggage as we are not absolutely obliged to take along with us. We shall therefore, for the present, leave the process of Dissolution entirely out of the account, or shall refer to it only incidentally, in cases where such a reference may assist in the elucidation of the counter-process. In the following chapter we shall have occasion to treat of Dissolution in some detail as exemplified in the probable future disintegration of our planetary system; at present we are concerned only with Evolution, which we have already seen to consist in the integration of matter and concomitant dissipation of motion, but which, as we shall presently see, implies in most cases much more than this. Let us first point out the conditions under which the secondary redistributions attending Evolution take place; and let us then proceed to point out the common characteristics of these secondary changes.

Obviously in speaking of secondary redistributions that go on while a body is integrating its matter and losing its motion, we refer to redistributions among the parts of the body and among the relative motions of the parts, — or, in other words, to alterations in structure and function going on within the body. Now the ease with which such redistributions are effected, and the ease with which they are maintained, must depend alike, though in precisely opposite ways, upon the amount of motion retained by the integrating body. The greater the amount of retained motion, the more easily will internal redistributions be effected. The smaller the amount of retained motion, the more easily will such redistributions be rendered permanent. These propositions are so abstruse as to require some further illustration.

When water is converted, by loss of its internal motion, into ice, the amount of secondary rearrangement which occurs among its particles is comparatively slight, but it is permanent so long as the state of integration lasts. During the continuance of the solid state there is not enough mobility among the particles to admit of further rearrangement to any conspicuous extent. On the other hand, after steam has been integrated into water, the retention of a considerable amount of molecular motion allows internal rearrangement to go on so easily and rapidly that no momentary phase of it has a chance to become permanent; and there can thus be no such stable arrangement of parts as we call structure. The phenomena of crystallization supply us with kindred, but slightly different examples. When a crystal is deposited from a solution, there is a certain point up to which the retention of motion keeps the crystal's molecules from uniting; but as soon as this point is passed, the motion is suddenly lost, the crystal solidifies, and there is no further redistribution of its particles. Conversely, when a molten metal is allowed to cool until it assumes a plastic semi-fluid state, its molecular motion is lost so slowly that a perceptible rearrangement of parts is possible: currents may be set up in it, gravity will cause it to spread out wherever it is not confined at the side, and pressure here and there will variously mould it.

But when it becomes solid, the rearrangements which occurred latest become permanent, and further rearrangements cannot be produced save by a fresh supply of molecular motion. In like manner, when we come to study planetary evolution, we shall find strong reasons for believing that on small bodies, like the moon and the asteroids, which have rapidly lost their internal heat, there has been but little chance for such complex secondary rearrangements as have occurred upon our relatively large and slowly cooling earth.

Even after the attainment of solidity, however, a new supply of motion from without may cause some further redistribution without causing the body to relapse into fluidity. Thus a wrought-iron rail, which when new is tough and fibrous, gradually acquires the brittle crystalline texture of cast-iron, under the influence of the vibrations communicated by the cars which pass over it. And the magnetization of steel rods, when fastened in the meridian and frequently jarred, is cited by Mr. Spencer as a fact of like import. Many other excellent illustrations, gathered from physics and chemistry, may be found in the thirteenth chapter of the second part of "First Principles." [1]

If now we contemplate in a single view the

[1] Throughout this work, reference is made only to the second and rewritten edition of *First Principles*, London, 1867.

general principles above illustrated, we shall seem for a moment to have got into difficulties. Unavoidably, in using the word Evolution, we have suggested the idea of increase in structural complexity; and such increase of course implies a considerable amount of permanent internal rearrangement as consequent upon the primary process of integration. Yet under the conditions thus far studied, we find that "on the one hand, a large amount of secondary redistribution is possible only where there is a great quantity of contained motion; and, on the other hand, these redistributions can have permanence only where the contained motion has become small — opposing conditions which seem to negative any large amount of permanent secondary redistribution." We must therefore search for some more peculiar and special combination of conditions before we can understand how Evolution may result in great structural complexity.

It is in the case of organic bodies "that these apparently contradictory conditions are reconciled; and that, by the reconciliation of them, permanent secondary redistributions immense in extent are made possible." The distinctive peculiarity of organic bodies "consists in the combination of matter into a form embodying an enormous amount of motion at the same

The statement of the law of evolution, as contained in the first edition, is much less complete and coherent.

time that it has a great degree of concentration." Let us enumerate the several ways in which organic bodies are enabled to retain vast quantities of molecular motion, without losing their high degree of concentration. The facts to be contemplated are among the most beautiful and striking facts which the patient interrogation of nature has ever elicited.

In the *first* place, while one of the four chief components of organic matter is carbon, a solid substance which cannot be fused by the greatest heat that man can produce, the other chief components — oxygen, hydrogen, and nitrogen — are gases which human art is unable to liquefy.[1] At a temperature of more than 200 degrees below the zero of Fahrenheit, and under a pressure so enormous as to shorten the steel piston employed, oxygen remains gaseous; and hydrogen and nitrogen display a like obstinate molecular mobility. Now, of these four substances, carbon has the most highly compounded molecule. In chemical language, the molecule of carbon is tetratomic, while that of nitrogen is triatomic, that of oxygen is diatomic, and that of hydrogen is monatomic. That is to say, a single molecule of carbon will hold in combina-

[1] [The later success of liquefaction in these cases has become within a short time a well-known fact of popular science. Fiske's text here was of course accurate at the time of writing.]

tion two molecules of oxygen, or four molecules of hydrogen; while three molecules of carbon will hold four molecules of nitrogen. It follows that in any organic compound, made up of the four above-named elements, a large number of molecules, possessing enormous mobility, must be held in combination by a relatively small number of molecules possessing little mobility. And since it is a corollary from the persistence of force that the sum of properties belonging to any compound must be the *resultant* of the properties belonging to its constituent elements, it follows that a compound molecule of organic matter must concentrate a great amount of motion in a small space. If, for example, we suppose ten molecules of carbon united with four of oxygen, eight of hydrogen, and eight of nitrogen, we shall have a compound in which ten immobile molecules hold together twenty highly mobile molecules. And while the twenty retain much of their mobility, the immobile ten prevent this mobility from disintegrating the compound.

Here we have reached a most beautiful and marvellous truth. If we now proceed, *secondly*, to follow out the way in which these quantitative relations are compounded, the case will appear still more remarkable. Instead of tens and twenties, we have to deal with hundreds of integrated molecules. Instead of such hypothetical cases as the one just cited, we have to contemplate real cases like the following. A single molecule of albumen is built up of two molecules of sulphur and one of phosphorus, compounded with ten organic molecules, of which each one contains forty molecules of carbon, five of nitrogen, twelve of oxygen, and thirty-one of hydrogen. Or, to reduce the statement to its simplest form, — in every molecule of albumen we have 1600 atomic equivalents of carbon, 150 of nitrogen, 240 of oxygen, 310 of hydrogen, 10 of sulphur, and 6 of phosphorus; making a grand total of 2316 atomic equivalents. And the molecule of fibrine is still more intricately compounded.

*Thirdly*, when we recollect that the simplest organic matter actually existing contains not one but very many albuminous molecules, and that these molecules are arranged, not in the crystalloid, but in the colloid form, — in "clusters of clusters which have movements in relation to one another," — we see still more clearly how vast must be the quantity of motion locked up within a small compass.

Our *fourth* item is perhaps the most remarkable of all. In the albumen molecule, the sum of all the atomic equivalents, except those of carbon, is 716. In order to hold these in combination, only 716 atomic equivalents of carbon would appear to be needed; yet we find 1600 equivalents. Why this apparent excess of carbon? The answer is to be found in the fact that nitrogen, unlike most other substances, absorbs heat on entering into combination. To the molecular motion which keeps it when free in a gaseous state, it adds a vast quantity of molecular motion. It has been calculated that the union of a pound of oxygen with nitrogen, in forming nitrous oxide, is attended by the absorption of enough heat to raise the temperature of 9232 pounds of water one degree Centigrade. It is probably owing to this peculiarity that nitrogen, which is so inert when free, is so wonderfully active when combined. Hence, too, we may understand the extreme instability of such nitrogenous substances as gunpowder, gun-cotton, and nitro-glycerine. And hence we may begin to discern the reason why nitrogen is the most important of the chemical elements concerned in maintaining vital activity. Now when we compare this property of nitrogen with the apparent excess of carbon in the albumen-molecule, we may fairly surmise that the two facts indicate a balance between the forces that tend to produce internal rearrangement and the forces that tend to prevent disintegration.

*Fifthly*, besides the fact that organic bodies usually possess an amount of heat which keeps their temperature somewhat above that of their inorganic environment, we have to note the fact that all organic matter is permeated by water. Hence, while sufficiently solid to preserve their continuity of structure, organic bodies are sufficiently plastic to allow of much internal rearrangement.

If we had time, it would be interesting to go on and trace the facts just enumerated through many complex exemplifications, and we might comment at length upon the significance of the facts that certain animals, as the *Rotifera*, lose their vitality when dried and regain it when wetted; that vital activity everywhere demands a supply of heat, and that the most complex organisms are in general the warmest; that animals contain more nitrogen than plants, and are at the same time more highly evolved; that carnivorous animals are relatively stronger and more active than herbivorous animals; that the parts of animals which are the seats of the highest vitality are mainly nitrogenous, while the more inert parts are mainly carbonaceous; that the highly nitrogenous matter composing the nervous system is nevertheless — as if to preserve the balance — always accompanied by inert carbonaceous fat; and that, while a nitrogenous diet renders possible the greatest quantity of physical and mental activity, at the same time carbonaceous alcohol retards the waste of nervous tissue.

But even without entering upon such a

course of illustration — which would oblige us to defer our main subject until another occasion — we are now enabled to see how it is that organic bodies can practically solve the dynamic paradox of acquiring a high degree of concentration, even while retaining an immense amount of motion. We are prepared to find, under these quite peculiar conditions, the structural rearrangements characteristic of Evolution carried on to a great extent. And we need not be surprised at finding these secondary phenomena here displayed so conspicuously as to obscure the significance of the primary phenomenon, integration. It was, in fact, through the study of organic phenomena by physiologists that a formula was first obtained for the most conspicuous features of Evolution; while the less obtrusive but more essential feature not only remained unnoticed until Mr. Spencer discerned it, but was not adequately treated even by him previous to the publication of his rewritten "First Principles," in 1867. I think it therefore advisable, in dealing with the law as generalized from organic phenomena, to begin by describing these most conspicuous features. We shall thus obtain a clearer view of the whole subject than we could well obtain in any other way. Having shown that Evolution is always and primarily an integration of matter attended by a dissipation of motion; and having shown that under certain conditions, most completely realized by organic bodies, certain secondary but equally important phenomena of structural rearrangement may be expected to accompany this fundamental process; we must next show what these secondary phenomena are.

The exposition will be rendered clearer by the preliminary explanation of four technical terms, which will continually recur, and which must be thoroughly understood before any further step can be taken toward comprehending the Law of Evolution. These terms are neither obscure in themselves, nor newly coined, but because we shall henceforth employ them in a strict and special sense, they require careful definition.

I. An object is said to be *homogeneous* when each of its parts is like every other part. An illustration is not easy to find, since perfect homogeneity is not known to exist. But there is such a thing as relative homogeneity; and we say that a piece of gold is homogeneous as compared with a piece of wood; or that a wooden ball is homogeneous as compared with an orange.

II. An object is said to be *heterogeneous* when its parts do not all resemble one another. All known objects are more or less heterogeneous. But, relatively speaking, a tree is said to be heterogeneous as compared with the seed from which it has sprung; and an orange is heterogeneous as compared with a wooden ball.

III. *Differentiation* is the arising of an unlikeness between any two of the units which go to make up an aggregate. It is the process through which objects increase in heterogeneity. A piece of cast-iron before it is exposed to the air is relatively homogeneous. But when, by exposure to the air, it has acquired a coating of ferric oxide, or iron-rust, it is relatively heterogeneous. The units composing its outside are unlike the units composing its inside; or, in other words, its outside is differentiated from its inside.

IV. The term *integration* we have already partly defined as the concentration of the material units which go to make up any aggregate. But a complete definition must recognize the fact, that, along with the integration of wholes, there goes on (in all cases in which structural complexity is attained) an integration of parts. This secondary integration may be defined as the segregation, or grouping together, of those units of a heterogeneous aggregate which resemble one another. A good example is afforded by crystallization. The particles of the crystallizing substance, which resemble each other, and which do not resemble the particles of the solvent fluid, gradually unite to form the crystal, which is thus said to be *integrated* from the solution. Integration is also seen in the rising of cream upon the surface of a dish of milk, and in the frothy collection of carbonic acid bubbles covering a newly filled glass of ale.

Obviously as it is through differentiation that an aggregate increases in *heterogeneity*, so it is through integration that an aggregate increases in *definiteness*, of structure and function. But there is still another way in which integration is exemplified. Along with increasing heterogeneity and definiteness of structure and function, the evolution of an aggregate is marked by the increasing subordination of the various functions, with their structures, to the requirements of the general functional activity of the aggregate. In other words, along with growing specialization of parts, there is a growing coöperation of parts, and an ever-increasing mutual dependence among parts. An illustration is furnished by the contrasted facts, that a slightly evolved animal, like a common earthworm, may be cut in two without destroying the life of either part; while a highly evolved animal, like a dog, is destroyed if a single artery is severed, or if any one of the viscera is prevented from discharging its peculiar functions. This third kind of integration is the process through which an evolving aggregate increases in *coherence*. And with this, our definition of the factors which concur in the process of evolution is complete.

We are now prepared to show inductively that wherever, as in organic aggregates, the conditions permit, *the integration of matter and concomitant dissipation of motion, which primarily constitutes Evolution, is attended by a continuous change from indefinite, incoherent homogeneity to definite, coherent heterogeneity of structure and function, through successive differentiations and integrations.* In illustration of this statement, let us describe first some of the differentiations, and secondly some of the integrations, which successively occur during the development of an individual organism.

Two centuries ago the researches of Harvey on generation established the truth that every animal at the outset consists simply of a structureless and homogeneous germ. Whether this germ is detached from the parent organism at each generation, as in all the higher animals, or only at intervals of several generations, as for example, in the *Aphides* or plant-lice, matters not to the general argument. In every case the primitive state of an animal is a state of relative homogeneity. The fertilized ovum of a lion, for instance, possesses at first no obvious characteristic whereby it can be distinguished from the fertilized ovum of a man, a dog, a parrot, or a tortoise. Each part of the germ-cell is, moreover, as nearly as possible like every other part, in molecular texture, in atomic composition, in temperature, and in specific gravity. Here in two ways we may notice how homogeneity is eventually succeeded by heterogeneity. In the first place all animal germs are homogeneous with respect to each other, while the animals developed from them present all kinds and degrees of diversity; and, in the second place, each germ is homogeneous with regard to itself, while the creature developed from it is extremely heterogeneous. The vegetable world exhibits a state of things essentially the same, though less conspicuous in its contrasts.

Starting from the homogeneous germ, we may follow out a parallel series of differentiations, resulting respectively in molecular rearrangements of chemical elements and in molecular and molar modifications of tissues and organs. The chemical differentiations have been so well and so concisely described by Mr. Spencer that I cannot do better than cite the passage entire: "In plants the albuminous and amylaceous matters which form the substance of the embryo give origin here to a preponderance of chlorophyll and there to a preponderance of cellulose. Over the parts that are becoming leaf-surfaces, certain of the materials are metamorphosed into wax. In this place starch passes into one of its isomeric equivalents, sugar;

and in that place into another of its isomeric equivalents, gum. By secondary change some of the cellulose is modified into wood; while some of it is modified into the allied substance which, in large masses, we distinguish as cork. And the more numerous compounds thus gradually arising initiate further unlikenesses by mingling in unlike ratios. An animal ovum, the components of which are at first evenly diffused among one another, chemically transforms itself in like manner. Its protein, its fats, its salts, become dissimilarly proportioned in different localities; and multiplication of isomeric forms leads to further mixtures and combinations that constitute many minor distinctions of parts. Here a mass darkening by accumulation of hæmatine, presently dissolves into blood. There fatty and albuminous matters uniting, compose nerve-tissue. At this spot the nitrogenous substance takes on the character of cartilage; and at that, calcareous salts, gathering together in the cartilage, lay the foundation of bone. All these chemical differentiations slowly and insensibly become more marked and more multiplied."[1]

The differentiations of tissues and organs are equally interesting. In the growth of any exogenous stem, the outer layer, or bark, first becomes distinguished from the woody interior.

[1] *First Principles*, p. 334.

Then while the bark gradually becomes differentiated into the liber, made up of woody tissue, the green and corky envelopes, made up of parenchyma, and the epidermis, the interior becomes differentiated into the pith, the medullary sheath, the woody layer, made up of bundles of greatly elongated cells, and the medullary rays, or what is called the *silver grain* in maple and oak. Meanwhile, between this heterogeneous bark and the heterogenous wood which it surrounds, there appears a zone of delicate cells, charged with dextrine and other assimilable matter, and known as the cambium layer. At the same time differentiations are going on at the upper extremity of this complicated structure. Portions of the green envelope protrude from between the liber and the epidermis, accompanied by tough fibres sent forth partly by the liber and partly by the woody layer. While the green portions flatten out horizontally, the fibres ramify through them and serve to stiffen them; and thus is developed the leaf, which, when mature, usually exhibits a further differentiation between blade and petiole, while by a continuance of the same process stipules often appear at the base of the petiole. Nor is this the end of the story. For while the chlorophyll-cells that make up the upper stratum of the leaf-tissue remain densely crowded, and are often covered by a wax-like cuticle, making the upper surface smooth and glossy; the cells composing the lower stratum become less and less crowded, until the result is a spongy surface, filled with innumerable pores, through which the moisture of the plant may be exhaled. Finally a differentiation arises between the axillary buds, some of which elongate into branches, repeating the chief characteristics of the stem, while others are developed under the still more heterogeneous forms of flowers, with their variously cleft calyx and corolla, and their variously compounded stamens and pistils.

In the fertilized mammalian ovum the earliest step toward heterogeneity consists in the division and redivision of the nucleated embryonic cell. As the cell-nucleus grows, by continuous integration of the nutritious protoplasm in which it is embedded, it slowly becomes grooved, and ultimately divides into a pair of nuclei, about each of which is formed a cell-wall. This process continues until the entire yolk is absorbed, by which time it has become differentiated into a mulberry-like mass of cells. And these cells, at first all alike spherical or nearly so, become club-shaped or hexagonal or pointed, as the mass further consolidates and squeezes them together. A grand differentiation next occurs between the outer and inner portions of the yolk-mass: the outer cells become flattened and pressed together, so as somewhat to resemble a mosaic pavement, and thus form a peripheral membrane. As this membrane continues to thicken by the integration of adjacent materials, it differentiates into two layers, wrapped the one within the other, like two coats of an onion. The outer layer, or ectoderm, absorbing larger quantities of nitrogenous matter than the other, is the one which by further immense differentiation is destined to produce the bony, muscular, and nervous systems; while the inner layer, or endoderm, is destined to produce the digestive apparatus. Between these two, by a further differentiation, arises a vascular layer, the rudiment of the circulatory system. Now on the interior surface of the endoderm appears a grooved channel, of which the edges gradually rise and fold over towards each other until joining they form a tube, — the primitive alimentary canal. At first nearly uniform, this channel becomes slowly more and more multiform. Near the upper end it bulges so as to form a stomach, while the long lower portion, variously wrapped and convoluted, is differentiated into the small and large intestines. From various parts of the now heterogeneous canal there bud forth variously organized secreting glands, — those which make saliva, and those which make gastric juice, bile-cells, pancreatic cells, and intestinal follicles. While from the exterior coat of the endoderm, thus wonderfully transformed, there shoot out, near the upper end, little flower-like buds, which by and by become lungs. In the intermediate or vascular layer, equally notable differentiations simultaneously occur. The vascular channels become distinguished as veins, arteries, and capillaries. "The heart begins as a mere aggregation of cells, of which the inner liquefy to form blood, while the outer are transformed into the walls." Presently the auricle, or chamber which receives blood, is differentiated from the ventricle, or chamber which expels it; and still later a partition-wall divides first the ventricle and afterwards the auricle into two portions — one for the venous, the other for the arterial blood. Along with all these changes, parallel processes, too numerous to be more than hinted at, are going on in the ectoderm. Masses of nitrogenous cells here give rise to muscles, which ramify through the whole interior of the embryo; and there to cartilaginous structures, in which deposits of earthy phosphate, hardening around certain centres, generate bone. The nervous system, first appearing as a mere groove upon the surface of the germinal membrane, finally exhibits an almost endless heterogeneity. First there is the difference between gray and white tissue, of which the first generates the peculiar kind of molecular motion vaguely termed nerve-force, while the latter transmits such motion. Then there are the differences between the nervous centres which, differently bundled together, make up the cerebrum, the cerebellum, the corpora quadrigemina, the medulla oblongata, the spinal cord, and the sympathetic ganglia, each of which aggregates is extremely heterogeneous in itself. And then there are the innumerable differences entailed by the highly complicated connections established between one nervous centre and another, by the inosculations of different sets of nerves with each other, and by the circumstance that some nerves are distributed upon muscles, others upon glands, and others upon ganglia.

These must suffice as examples of differentiation. To go on until we had exhausted the series of differentiations which attend the evolution of a single individual would be to write the entire history of an organism — and thus to convert our philosophic discussion into a special scientific monograph. That history was long since thoroughly written by Von Baer. Following out the hints furnished by Linnæus, K. F. Wolff, Goethe, and Schelling, this illustrious embryologist announced in 1829 his great discovery that the progressive change from homogeneity to heterogeneity is the change in which organic evolution essentially consists. It was this formula which Mr. Spencer began, some twenty years later, to extend into the universal law of evolution. But, far from having anticipated the essential portion of Mr. Spencer's discovery, Von Baer's formula stands in much the same relation to it in which the speculations of Copernicus stood with reference to the discovery of Newton. Just as Copernicus was essentially in error in maintaining that the planets revolve in circular orbits, Von Baer was essentially in error in considering the process of differentiation as the fundamental characteristic of evolution, as well as in ignoring the process of integration. The whole foregoing exposition has shown, and the entire remainder of the exposition will still further convince us, that the fundamental characteristic of evolution is integration of matter with dissipation of internal motion; and that the change from homogeneity to heterogeneity is but the secondary rearrangement which results wherever the retained motion is great enough to allow it.

Still more, in ignoring the process of integration, Von Baer failed to include in his formula that change from indefiniteness and incoherence to definiteness and coherence, which is equally important with the change from homogeneity to heterogeneity. In the evolution of an organic germ, integration is just as essential a part of the whole process as differentiation. If the latter were alone to take place, the result would simply be a chaotic medley of organs and tissues. Both operations are requisite to produce a system of organs capable of working in concert. And if differentiation goes on, unattended by integration, in any part of the body, disease, and often death, is the result. Cancers and malignant tumours are merely indefinite results of differentiation, which, never becoming integrated into harmony with the rest of the organism, end by maiming and finally destroying it. As Dr. Beale has shown, a cancer is a new variety of cellular tissue, fungoid in character, which grows at the expense of the organism, and eats it up as effectually as a carnivorous enemy could eat it. To employ an instructive metaphor, a cancer is a rebellion within the organism, — a setting up of an independent centre of government, — a fatal interference with the subordination of the parts to the whole. Yet the organism in which a cancer has begun to grow is more heterogeneous than the healthy organism. In like manner the first stages of decomposition increase the heterogeneity of the organism as a whole; but because each new retrograde product follows henceforth a career of its own, free from the control of the organic aggregate, the result is not evolution, but dissolution. The differentiations which occur during the normal growth of the germ differ from those which constitute cancer and gangrene, alike in their common subordination to the primary process of growth, and in the definiteness of the resulting structures. "In the mammalian embryo, the heart, at first a long pulsating blood-vessel, by and by twists upon itself and integrates. The bile-cells constituting the rudimentary liver do not simply become different from the wall of the intestine in which they at first lie; but as they accumulate, they simultaneously diverge from it, and consolidate into an organ. The anterior segments of the cerebro-spinal axis, which are at first continuous with the rest, and distinguished only by their larger size, undergo a gradual union; and at the same time the resulting head folds into a mass clearly marked off from the rest of the vertebral column. The like process, variously exemplified in other organs, is meanwhile exhibited by the body as a whole — which becomes integrated somewhat in the same way that an outspread handkerchief and its contents become integrated when its edges are drawn in and fastened to make a bundle." Mr. Spencer, from whom I have quoted this embryologic illustration, goes on to cite parallel instances in the development of lower forms of animal life; a few of which may be here epitomized. In the growth of the lobster from its embryo, a number of calcareous segments, originally separable, become integrated into the compact boxes which envelop the organs of the head and thorax. A similar concentration occurs in the spider, the bee, and the butterfly. In contrast with this, we may profitably observe what goes on in many annuloid worms, where the multiplication of segments by differentiation results in the fission of the animal into two distinct individuals, because the integrating power of the organism is slight.[1] Similarly in

[1] Here, without prejudice to the general argument, I may call attention to the very ingenious hypothesis propounded by Mr. Spencer, to account for the origin of the annulose or articulated sub-kingdom of animals. According to this hypothesis, any annulose animal is in reality a compound organism, each of its segments representing what was originally a distinct individual. In other words, an annulose animal is a colony or community of animals which have become integrated into an individual animal. Strong *prima facie* evidence of such a linear joining of individuals primevally separate is furnished by the structure of the lowest annelids. Between the successive segments there is almost complete identity, both internal and external. Each segment is physiologically an entire creature, possessing all the organs necessary for individual completeness of life; not only legs and bronchiæ of its own, but also its own nerve-centres, its own reproductive organs, and frequently its own pair of eyes. In many of the intestinal worms each segment has an entire reproductive apparatus, and being hermaphrodite, constitutes a complete animal. Moreover in the development of the embryo the segments grow from one another by fission or gemmation, precisely as colonies of compound animals grow. At the outset the embryo annelid is composed of only one segment. The undifferentiated cells contained in this segment, instead of being all employed in the formation of a heterogeneous and coherent structure within the segment, as would be the case in an animal of higher type, proceed very

the development of the higher crustaceans, the parallel chains of ganglia, which constitute the

soon to form a second segment, which, instead of separating as a new individual, remains partially attached to the first. This process may go on until hundreds of segments have been formed. Not only, moreover, does spontaneous fission occur in nearly all the orders of the annulose sub-kingdom, but it is a familiar fact that artificial fission often results in the formation of two or more independent animals. So self-sufficing are the parts, that when the common earth-worm is cut in two, each half continues its life as a perfect worm, — as is above observed, in the text. Very significant, too, is the fact that in some genera, as in chætogaster, where the perfect individual consists of three segments, there is formed a fourth segment, which breaks off from the rest and becomes a new animal.

All these facts, together with many others of like implication, point to the conclusion that the type of annulosa has arisen from the coalescence, in a linear series, of little spheroidal animals primevally distinct from one another. How are we to explain, or classify, such a coalescence? May we not most plausibly classify it as *a case of arrested reproduction by spontaneous fission?* In other words, whereas the aboriginal annuloid had been in the habit of producing by gemmation a second individual which separated itself at a certain stage of growth, there came a time when such separation became arrested before completion; so that, instead of a series of independent organisms, the result was a colony of organisms linked together in a linear chain. Let us observe that by this brilliant explanation the origin of the annulose type is completely assimilated to the origin of the lowest animal and vegetal types. The primordial type alike of the vegetable and of the animal is a single spherical or spheroidal cell, which reproduces itself by spontaneous fission. That is, it elongates until room is made for a second nucleus, after which a notch appears in the nervous system of the embryo, unite into a single chain. The same kind of integration may be traced in the nervous systems of insects; and the reproductive system of the vertebrata

cell-wall between the nuclei; and this notch deepens until the old and new cells are quite separated from each other. Now when many such primordial cells are enclosed in a common membrane, so that, instead of achieving a complete separation, they multiply into a jelly-like or mulberry-like mass, there is formed — whether the case be taken in the animal or in the vegetal kingdom — an organism of a type considerably higher than the simple cell. There is an opportunity for differently conditioned cells comprised in the same mass to become differently modified, and thus to subserve various functions in the economy of the organism. There is a chance for division and combination of labour among the parts. Now the progress achieved when the spheroidal members of an annuloid compound remain partly connected, instead of separating, is precisely similar to this. Among the indubitably compound animals of cœlenterate or molluscoid type, in which the fission is not arrested, it is but seldom that the individuals stand related to one another in such a way that there can be any need of their severally performing diverse and specialized functions. For instance, among the hydrozoa, each member of the compound can get food for itself, can expand or contract its tentacles in any way without affecting the general welfare of the compound. But now, if the members of such a compound as the hypothetical primitive annuloid are grouped in a linear series, there must arise a difference between the conditions which affect the extreme members of the series, and the conditions which affect the intermediate members. And consequently there will ensue an advantage to the compound in the struggle for life, if the members, instead of continuing to perform identical functions separately, become sufficiently united to allow of their per-furnishes like instances of coalescence which are so conspicuous that they are now usually made one of the primary bases of classification

forming different functions in concert. Hence we obtain the lowest actual type of annuloid, in which the segments are mere repetitions of each other, with the exception of the extreme front and rear segments, which subserve different functions related to the welfare of the aggregate.

Viewed in this light, the various great classes of the annulose sub-kingdom beautifully illustrate that progressive coördination of parts becoming more and more unlike one another, which is the chief characteristic of Evolution as displayed in the organic world. In very low annelids, such as the intestinal worms, we see hardly any specialization among the parts ; and as we proceed upwards through the lower types, ending with the myriapoda, we meet with a great but varying number of segments, which show but little specialization save in the head and tail. The same is true in general of the larvæ and caterpillars of the higher types. But as we rise to the adult forms of the insect-group — comprising crustaceans, arachnoids, and true insects — we find the number of segments reduced to just twenty. And while this number remains unvarying, the modifications undergone by different segments in conformity to the requirements of the aggregate are almost endless in variety, the extremes, both of concentration and of specialization, being seen in the ant, the spider, and the crab. In many of the details of this gradual fusion of distinct individuals into a coherent whole, we see the hypothesis interestingly illustrated and justified. In the annelids of low type, each segment has its own spiracles which have no internal communication with one another. On the other hand, in the insect-group there is a complete system of vessels connecting the respiratory systems. While in the intermediate myriapoda we find, as might be expected, a partial communication.

in this sub-kingdom. The reason why Von Baer overlooked this essential process is probably to be found in the fact that each secondary integration, resulting in increased definiteness, serves to make the accompanying differentiation still more prominent. The differentiation of lungs, for instance, from the outer coat of the endoderm, becomes marked in proportion as the flower-like buds become integrated into organs of definite contour. But while the two correlative processes go on hand in hand, it is none the less true that they are distinct processes, and that a comprehensive formula of evolution must explicitly describe them both.

In further illustration of this twofold aspect of evolution, we may cite a fact which will by and by be seen to have other important bearings, but which may here serve as a valuable appendix to the foregoing discussion. This is the fact that, in ranking different organisms as high or low in the scale of life, we always proceed chiefly with reference to the degree of heterogeneity, definiteness, and coherence which they exhibit. Those plants and animals which we rank as lowest in the scale are simply cells, like the homogeneous cells from which higher plants and animals are developed. So little specialized are these forms that they do not exhibit even those characteristics by which we ordinarily distinguish between vegetal and animal life. As we ascend the vegetal scale, we find the ferns and lichens decidedly more heterogeneous than the algæ; and as we meet with endogens and exogens, we find the increasing heterogeneity accompanied by a definiteness and coherence of structure that is ever more and more conspicuous. Going up the animal scale, we find the annulosa, on the whole, much more heterogeneous, definite, and coherent than the mollusca; while the vertebrata, on the whole, exhibit these characteristics more strikingly than either of the other sub-kingdoms. The relatively homogeneous and unintegrated polyps are ranked below all of these. Within each group the same principle of classification is universally followed. Contrast the centipede, whose multitudinous segments are almost literally copies of each other, or the earthworm, which may be severed in the middle and yet live, with the highly differentiated and integrated hive-bee, spider, or crab. Compare the definite and symmetrical contour of the cuttlefish, which is the highest of the mollusca, with the unshapely outline of the molluscoid ascidians. Or, to cite cases from the two extremes of the animal scale, consider first the complicated mammal, whose growth from the embryo we have lately contemplated; and then turn to the hydra, or fresh-water polyp, which is a mere bag of organized matter, digesting with its inner surface and respiring with the outer, — yet so little specialized that, if turned inside out, the digestive surface will begin to respire, and the respirative surface to digest, as imperturbably as if nothing had happened. In short, in a survey of the whole organic world, progress from lower to higher forms is a progress from forms which are less, to forms which are more, differentiated and integrated.

One further point must be noticed before we conclude this preliminary sketch of the process of evolution. The illustrations above given refer almost exclusively to differentiations and integrations of *structure*, or, in other words, to rearrangements of the *matter* of which organic bodies are composed. It remains to be shown how the rearrangements of the *motion* retained by developing organisms exhibit the same characteristics, and manifest themselves as differentiations and integrations of *function*. All organic functions are either molar motions of contractile muscles, or of circulatory fluids, or else they are molecular motions in nerves, or in secreting organs, or in assimilative tissues in general. To show how these various motions become more specialized and more consolidated as the organism is developed, let us briefly reconsider the case of the alimentary canal, whose structural modifications were lately described. The primitive alimentary canal exhibits from end to end a tolerably uniform series of molar motions of constriction. But as the canal becomes more heterogeneous, the molar movements in its different parts simultaneously become more unlike one another. While the waves of contraction and expansion remain constant and moderate throughout the small intestine, they are replaced in the œsophagus by more violent contractions and expansions that recur at longer rhythmical intervals. In the stomach the mechanical undulations are so much more powerful as to triturate the contained food, and their rhythms are differently compounded; while the movements of the mouth are still further specialized in the actions of biting and chewing. In the molecular motions constituting secretion and absorption there is a similar specialization. While absorption is confined chiefly to the area covered by the lacteals, secretion is specialized in various localities — in the salivary glands, in the gastric and intestinal follicles, in the liver, and in the pancreas — and in each place it has acquired a peculiar character. A like increase in heterogeneity and definiteness marks the circulatory movements. In a slightly evolved animal the nutritive fluid, answering to blood, moves about here and there at seeming random, its course being mainly determined by the local pressure of the tissues. But in a highly evolved animal, which possesses a well-developed vascular system, the blood runs in definite channels, and with well-marked differences of movement. Its movement is slow and continuous in the capillaries, fast and continuous in the veins, still faster but discontinuous in the arteries; while the rhythms in all are subordinated by the central rhythm of the heart. Still more remarkable, in the most complex organisms, is that kind of functional integration which consists in the mutual dependence of different functions. Neither alimentation nor circulation nor respiration can go on alone; and all three are dependent upon the continuance of nervous action, which in turn depends alike upon each of the three. A few whiffs of tobacco, for example, setting up slight molecular changes in the medulla oblongata, increase the heart's rate of pulsation, and stimulate every one of the alimentary secretions, while it is probable also that, through the medium of the sympathetic ganglia, the sectional area of every artery is slightly altered. The cautious physician, in prescribing a powerful drug, knows that he is dealing with an integration of motions so extensive that the disturbance of any one will alter the directions and composition of all the others to a degree which baffles accurate calculation. Contrasting with such cases as these the homogeneous, indefinite and uncombined movements of those lowest animals, that are borne hither and thither by the vibrations of cilia, it becomes evident that the formula which expresses the structural evolution of matter expresses also the functional evolution of the motion which the integrating matter retains.

Embracing now in one general view the various kinds of transformation exemplified in the present chapter, we find that our survey of organic development completely justifies Mr. Spencer's technical statement, — "*Evolution is an integration of matter and concomitant dissipation of motion, during which the matter passes from an indefinite, incoherent homogeneity to a definite, coherent heterogeneity; and during which the retained motion undergoes a parallel transformation.*" [1]

Here, it will be observed, we have obtained a formula which applies not to organic development merely, but to the transformations of Matter and Motion in general. Though we have been led to it solely by the consideration of those organic phenomena which, for reasons already presented, most conspicuously exemplify it, and in connection with which it was first partially generalized by Goethe and Von Baer; yet now that we have arrived at this formula, we find ourselves expressing it in terms that are universal. Instead of a mere law of biology,

[1] *First Principles*, p. 396.

we have enunciated the widest generalization that has yet been reached concerning the concrete universe as a whole. Having ascertained that in organic aggregates, where the conditions are such as to allow of relatively permanent structural rearrangements, the process of Evolution is characterized by a change from indeterminate uniformity to determinate multiformity, we have assumed that like conditions will everywhere be attended with like results. The law asserts that wherever a relatively permanent system of rearrangements is possible, whether in organic or in inorganic aggregates, the change from indeterminate uniformity to determinate multiformity will be manifested. This leap of inference on Mr. Spencer's part, like the similar leap taken by Newton from the fall of the apple to the motions of the moon, is the daring act which completes the formation of the hypothesis. This grand hypothesis we must now proceed to verify by showing that the widest generalizations severally obtainable in the concrete sciences are included in it, and receive from it their common interpretation. It is to be shown that in the case of sundry inorganic aggregates or systems of parts (forming the subject-matter of astronomy and geology), where circumstances not yet recounted permit the retention of a considerable relative motion of parts, the processes of differentiation and integration are quite conspicuously manifested; although, as we might expect, these processes are never carried so far here as in the case of organic aggregates. It will next be shown that the hypothesis is verified, alike by the scanty facts which are at our disposal concerning the genesis of Life, and by the enormous multitude of facts which prove beyond the possibility of doubt that the more complex living creatures have originated by physical derivation from ancestral creatures that were less complex. Next, although — as I have already remarked — the phenomena of Mind are in no sense identifiable with material phenomena, yet as in all our experience there is no manifestation of Mind which is not mysteriously conditioned by movements of matter, we shall find that these super-organic phenomena do not fail to conform to the universal law. It will be shown that the development of conscious intelligence, alike in the individual and in the race, is characterized by the change from indeterminate uniformity to determinate multiformity. The history of the products of conscious intelligence exemplify the same principle; and nowhere shall we find more striking confirmation than is furnished by the phenomena of social progress. By the time we have narrated the results of this vast induction, we shall be convinced that "from the earliest traceable cosmical changes down to the latest products of civilization," the law of organic evolution here expounded is the law of all evolution whatever.

But the universality of this law admits of deductive proof which may properly be adduced while concluding this chapter, and before entering upon the long course of inductive verification which comes next in order. Already we have seen that the changes which primarily constitute Evolution are necessitated by the rhythm of motion, and therefore indirectly by the persistence of force. We have now to show how the secondary changes, differentiation and integration, are equally necessitated by the same primordial fact.

It is a corollary from the persistence of force, "that, in the actions and reactions of force and matter, an unlikeness in either of the factors necessitates an unlikeness in the effects." When the different portions of any homogeneous aggregate are exposed to the action of unlike forces, or to unequal intensities of the same force, they are of necessity differently affected thereby. Between the unequally exposed parts there arise structural differences, entailing differences of property and function. That which before was homogeneous has become heterogeneous through the appearance of certain unlikenesses, — and, under the name of differentiation, the rise of such unlikenesses has already been described.

It remains to be observed that such unlikenesses cannot but arise, that differentiation must needs take place, because it is impossible for all the parts of any aggregate to be similarly conditioned with reference to any incident force. Whether it be the mechanical vibrations caused by a blow, the slow undulations constituting heat, or the more rapid undulations constituting light, that are propagated through any body, it equally follows that the respective vibrations will be communicated in different degrees to those particles which are situated on the nearer and on the farther side of the body, and to those particles which are laterally near to or remote from the line followed by the incident force. The different parts will be variously moved, heated, or chemically affected, and a series of differentiations will thus have arisen. We need go no farther than the kitchen, to perceive that the crust formed on a loaf of bread or a joint of roasted meat, is due to the necessary unequal exposure of outside and inside to the incident force coming in the shape of heat from the walls of the oven. In the impossibility of balancing an accurately made pair of scales, in the equal impossibility of keeping a tank of water free from currents, in the rusting of iron, and in the uneven cooling of a heated metal, is exemplified the principle that the state of homogeneity is an unstable state.

Universally the tendency of things, amid the conflict of unlike forces, is toward heterogeneity.

Coincident with the differentiation of aggregates, there is a differentiation of the incident forces. When a moving body is broken up by collision, its original momentum is severed into a group of momenta, which differ both in amount and in direction. The ray of solar light which falls upon the foliage of a tree and upon the wall of the brick building behind it, is separated by reflection into red and green rays, in which the undulations differ both in height and in breadth. Each portion of the differentiated force must in its turn enter as a factor into new differentiations. The more heterogeneous an aggregate becomes, the more rapidly must differentiation go on; because each of its component units may be considered as a whole, bearing relations to the other units similar to those which the aggregate bears to other aggregates; and thus the differentiation of the whole must be followed by the differentiation of the parts. There must thus be a multiplication of effects as heterogeneity increases; because, with increasing heterogeneity, the forces which bodies and parts of bodies mutually exert upon each other must become ever more varied and complex in their amounts and directions.

We may see, therefore, that differentiation is a necessary consequence of the fundamental relations of matter and motion. And the same is true of that secondary integration or union of like units, which serves to render differentiation more conspicuous by substituting a demarcated grouping for a vague one. Considering what happens when a handful of pounded sugar, scattered before the breeze, falls here and there according to the respective sizes of the fragments, — we perceive that the units which descend in company are those of equal size, and that their segregation results from their like relations to the incident force. The integration of several spinal vertebræ into a sacrum, as the result of exposure to a continuous strain in the same direction, is a still better example; and from the phenomena of morphological development many parallel cases might be cited. Wherever different parts of any group of units stand in different relations to an incident force, differentiation must result; and wherever any sub-group of these units, after becoming unlike the rest, is acted on by a common force, the result must be the integration of the sub-group. But manifestly the primary process of consolidation cannot long go on in any aggregate, without bringing sundry groups of units into dissimilar relations to adjacent groups; nor can it long go on without subjecting each group, thus differentiated, to a predominant force exerted by the totality of the companion groups. Hence the change from indefinite incoherent homogeneity to definite coherent heterogeneity must accompany the integration of matter ; and no alternative conclusion can be reached without denying the persistence of force.

I am aware that scanty justice is here done to the arguments by which, in three interesting chapters, Mr. Spencer establishes this deductive conclusion. But since the brief exposition here given is not intended as a substitute for the study of Mr. Spencer's treatise, but rather as a commentary upon it, his position has been perhaps sufficiently indicated.

We are now prepared to study with profit some of the phenomena presented by the past history of our planetary system. In the evolution of the sun, with his attendant planets and satellites, from a vast primeval mass of vapour, we shall be called upon to witness a grand illustration not only of that integration of matter and concomitant dissipation of motion which is the fundamental characteristic of Evolution in general, but also of that change from indefinite and incoherent homogeneity to definite and coherent heterogeneity which is its most striking derivative feature.

# CHAPTER V

## PLANETARY EVOLUTION[1]

AMONG the notable phenomena presented by the structure of our planetary system, there are some which have become so familiar to us that we commonly overlook them altogether, and through sheer inattentiveness fail to realize their significance. For example, all the planets revolve about the sun in the same direction, which coincides with the direction of the sun's own rotation upon his axis. All the planets, moreover, revolve in planes which are but slightly inclined to the plane of the sun's equator. Satellites conduct themselves similarly with reference to their primaries. Every satellite revolves about its primary in the direction of the primary's axial rotation, and in a plane but little inclined to the plane of the primary's equator. Again, with the single interesting exception of Uranus — and possibly also of Neptune — all the planets, as well as the sun, rotate upon their axes from west to east, in the same direction with their orbital revolutions. And lastly, all the planets, both primary and

[1] [See Introduction, § 16.]

secondary, move in elliptical orbits of small or moderate eccentricity.

We are so accustomed to acquiesce in these facts, as if they were ultimate, that we seldom stop to consider them in their true light, as unimpeachable witnesses to the past history of the solar system. Yet as Laplace has shown, it is practically impossible that such harmonious relations should hold between the various members of the solar system, unless those members have had a common origin.

The clue to that common origin may be sought in facts which are daily occurring before our very eyes. Every member of our planetary system is constantly parting with molecular motion in the shape of heat. Our earth is incessantly pouring out heat into surrounding space; and, although the loss is temporarily made good by solar radiation, it is not permanently made good, — as is proved by the fact that during many millions of years the earth has been slowly cooling. I do not refer to the often-cited fact that the Arctic regions were once warm enough to maintain a tropical vegetation; for this high temperature may well have been due to minor causes, such as the greater absorptive power of the ancient atmosphere with its higher percentage of carbonic acid and ozone. Nor need we insist upon the alleged fact that extensive glaciation appears to have been unknown until a comparatively late epoch; although glaciation, whether brought about by changes in the distribution of land and sea or by a variation in the eccentricity of the earth's orbit, certainly does seem to imply a progressive dependence of the earth upon the supply of solar heat, due to the lowering of its own proper temperature. Such facts, however, are wholly inadequate to describe the primitive heat of the earth. The flattening of the poles being considerably greater than could have been produced by the rotation of a globe originally solid on the surface, it follows that the whole earth was formerly fluid. And this conclusion, established by dynamical principles, is uniformly corroborated by the observed facts of geology. Now the fluidity of the entire earth, with its rocks and metals, implies a heat sufficient to have kept the planet incandescent, so that it must have shone with light of its own, like the stars. Similar conclusions are indicated by the observed geologic features of Mars and Venus; and in the case of the moon we shall presently see what a prodigious loss of heat is implied by the fact that the forces which once upheaved its great volcanoes are now quiescent. The sun, too, is pouring away heat at such a rate that, according to Sir John Herschel, if a cylinder of ice 184,000 miles in length and 45 miles in diameter were darted into the sun every second, it would be melted as fast as it came. Or, as Mayer has calculated, the amount of heat lost every minute by the sun would suffice to raise the temperature of thirteen billion cubic miles of water one degree Centigrade. Although this prodigious loss is perhaps partly compensated by heat due to the arrested motion of meteors falling upon the sun's surface, yet it is by no means probable that it is in this way compensated to any noteworthy extent. It is in every way indisputable that from time immemorial sun, moon, and earth, as well as the other members of our system, have been parting with their internal motion, in the shape of heat radiated into surrounding space.

Thus in the history of our planetary system we may already begin to witness that dissipation of motion which has been shown to be one of the prime features of the process of Evolution, wherever exemplified. But, as we have also seen, the dissipation of motion is always and necessarily accompanied by the concentration of matter. It is not simply that, with two or three apparent exceptions, which have no bearing upon the present argument, all cooling bodies diminish in size and increase in density; but it is also that all contracting bodies generate heat, the loss of which, by radiation, allows the process of contraction to continue. In any contracting mass the particles which tend toward the common centre have their molar motions constantly opposed by friction upon each other, and most of the motion thus arrested is converted into heat. If this heat is lost by radiation as fast as it is thus generated, the contraction of the mass will go on unceasingly. It is in this way that physicists now account for the internal heat of the sun and the planets. A diminution of the sun's diameter by the amount of twenty miles could not be detected by the finest existing instruments; yet the arrest of motion implied in this slight contraction would generate enough heat to maintain the present prodigious supply during fifty centuries. And in similar wise the internal heat of the earth during a given moment or epoch must be chiefly due to that very contraction which the radiation of its heat during the preceding moment or epoch has entailed.

The generation of all this heat, therefore, which sun and planets have from time immemorial been losing, implies the transformation of an enormous quantity of molar motion of contraction. It implies that from time immemorial the various members of our planetary system have all been decreasing in volume and increasing in density; so that the farther back in time we go, the larger and less solid must we suppose them to have been. This is an inevitable corollary from the companion laws that contracting bodies evolve heat, and that radiating bodies contract.

Obviously, therefore, if we were to go back far enough, we should find the earth filling the moon's orbit,[1] so that the matter now composing the moon would then have formed a part of the equatorial zone of the earth. At a period still more remote, the earth itself must have formed a tiny portion of the equatorial zone of the sun, which then filled the earth's orbit. At a still earlier date, the entire solar system must have consisted simply of the sun, which, more than filling Neptune's orbit, must have consisted of diffused vaporous matter, like that of which the irresolvable nebulæ have recently been proved to consist. Now in the slow concentration of the matter constituting this solar nebula, as both Kant and Laplace have elaborately proved, the most prominent peculiarities of the solar system find their complete explanation. Supposing the sun to have been once a mass of nebulous vapour, extending in every direction far beyond the present limits of the solar sys-

[1] It is not presumed, however, that the moon's orbit was originally so large as at present. For by its tidal action upon our oceans the moon exerts a drag upon the earth's rotation, and the motion thus lost by the earth is added to the moon's tangential momentum, thus increasing the dimensions of its orbit. A precisely similar qualification is needed for the two next succeeding statements in the text.

tem, these thinkers proved that the mere contraction of such a mass must inevitably have brought about just the state of things which we now find. Let us observe some of the processes which must have taken place in this nebulous mass.

Note first that we are obliged to accredit the various parts of this genetic nebula with motions bearing some reference to a common centre of gravity; for the rotation of the resulting system must have had an equivalent amount of motion for its antecedent, and it is a well-known theorem of mechanics that no system of bodies can acquire a primordial rotation merely from the interaction of its own parts. In making this assumption, however, we are simply carrying out the principle of the continuity of motion. It is not necessary to suppose, in addition, that all these motions primordially constituted a rotation of the whole mass in one direction. Such a hypothesis seems to me not only gratuitous, but highly improbable. It is more likely that these primeval motions took the shape of currents, now aiding and now opposing one another, and determined hither and thither according to local circumstances. In any case, such indefiniteness of movement must finally end in a definite rotation in one direction. For unless the currents tending eastward are exactly balanced by the currents tending westward — a supposition against which the chances are as infinity to one — the one set must eventually prevail over the other. And after some such manner as this our solar nebula must have acquired its definite rotation from west to east.

Let us next observe the mechanical consequences of this rotation. No matter what may have been the primitive shape of the nebula — and, if we may judge from the analogy of irresolvable nebulæ now existing, it may very likely have been as amorphous as any cloud in a summer sky — no matter what its primitive shape, it must at last inevitably assume the form peculiar to rotating bodies in which the particles move freely upon each other. It must become an oblate spheroid, flattened at the poles and bulging at the equator, because at the equator the centrifugal tendency generated by rotation is greatest. Furthermore, as the mass contracts it must rotate faster and faster; for as the total quantity of rotation is unalterable, the velocity must increase as the space traversed diminishes.

In accordance with these principles of mechanics, as our solar nebula continued to radiate heat and contract, it continued to rotate with ever-increasing velocity, its poles became more and more flattened, and its equatorial zone protruded more and more, until at last the centrifugal tendency at the equator became greater than the force of gravity at that place. Then the bulging equatorial zone, no longer able to keep pace with the rest of the mass in its contraction, was left behind as a detached ring, girdling, at a small but steadily increasing distance, the retreating central mass.

What must now have been the career of this detached ring? Unless subjected to absolutely symmetrical forces in all directions — an infinitely improbable supposition — such a ring must forthwith break into a host of fragments of very unequal dimensions. For in order that it should break into equal-sized fragments, the strains exerted upon it must be disposed with absolute symmetry; and against this supposition also the probabilities are as infinity to one. It would break, much as a dish breaks when dropped on the floor, into hundreds of fragments, of which some few would be relatively large, while the numerous small ones would vary endlessly in their sizes. At this stage, then, instead of a continuous ring, we have a host of satellites, surrounding the solar equator, revolving in the direction of the solar rotation, and following each other in the same orbit. If undisturbed by any powerful attraction from without, these fragments would continue in the same orbit, and would gradually differ more and more in their velocities. Each large fragment would, by its gravitative force, retard the smaller fragment in front of it, and accelerate the smaller fragment behind it, until at last two or three fragments would catch up with each other and coalesce. Thus, in the earliest case known to us, — that of the planet Neptune,[1] — this process went on until all the fragments were finally agglomerated into a spheroidal body, having a velocity compounded of the several velocities of the fragments, and a rotation made up of their several rotations.

Meanwhile the central mass of the vaporous sun continued to radiate heat and to contract, until, when its periphery came to coincide with what is now called the orbit of Uranus, its centrifugal force at the equator again showed an excess over gravity, and a second equatorial belt was left behind; and this belt, breaking up and consolidating, after the manner above described, became the planet Uranus. In like manner were formed all the planets, one after another; and from the detached equatorial belts of the cooling and contracting planets were similarly formed the satellites.

A very curious physical experiment, devised

1 It is not strictly impossible that there may be one or two planets exterior to Neptune, and therefore earlier in formation. Supposing the distances of such planets to conform, even as imperfectly as in Neptune's case, to the law of Titius, these distances must be so enormous as to prevent our readily discovering the planets, either directly by observation, or indirectly, by inference from possible perturbations of Neptune's movements.

by M. Plateau, strikingly illustrates the growth of our planetary system from the solar nebula. M. Plateau's experiment consists in freeing a fluid mass from the action of terrestrial gravity, so that its various parts may be subject only to their own mutual attractions; and then in imparting to this mass an increasingly rapid movement of rotation. A quantity of oil is poured into a glass vessel containing a mixture of water and alcohol, of which the lower strata are heavier than the oil, while the upper strata are lighter. The oil, when poured in, descends until it reaches the stratum of the same density with itself, when being freed from the action of terrestrial gravity, and subjected only to the mutual attraction of its own molecules, it assumes a spherical form. By an ingenious mechanical contrivance, M. Plateau now causes the sphere of oil to rotate about its own centre of gravity. While the movement is slow, the excess of centrifugal force at the equator of the oil-globe causes a bulging of the equator and corresponding flattening of the poles, like that observed in the sun and in all the planets. From a sphere the oil-globe becomes a "spheroid of rotation." If now the movement is considerably accelerated, the equatorial portion of the oil-globe becomes detached, and surrounds the central sphere of oil in the shape of a nearly circular ring, like Saturn's ring-system. Finally, if the movement is kept up for a sufficient length of time, the oil-ring breaks into fragments, which revolve like satellites about the oil-globe, and each of which keeps up for a time its own movement of rotation in the same direction with the revolution of the ring.

The common origin of the planets from the sun's equator, as thus strikingly illustrated, explains at once the otherwise inexplicable coincidence of their rotations, their revolutions, and their orbital planes. At a single glance we see why the planetary orbits are always nearly concentric and nearly in a plane with the solar equator; and we see that, since the sun must always have rotated, as at present, from west to east, the planets formed from him must have kept up a revolution, and acquired a rotation, in the same direction.

Such is the grand theory of nebular genesis, first elaborated with rare scientific acumen by Kant in 1755, and afterwards independently worked out by Laplace in 1796. The claims of this theory to be regarded as a legitimate scientific deduction have been ably stated by Mr. Mill, in his "System of Logic," Book III. chapter xiv. As we are there reminded, "there is in this theory no unknown substance introduced on supposition, nor any unknown property or law ascribed to a known substance." Once grant that the sun and planets are cooling bodies, the inference is unavoidable that the matter which composes them was formerly much more rare and diffused than at present. If we are to infer the sun's past condition from its present condition, we must necessarily suppose that its constituent matter once occupied much more space than at present, "and we are entitled to suppose that it extended as far as we can trace effects such as it might naturally leave behind it on retiring; and such the planets are." The abandonment of successive equatorial zones by the shrinking solar nebula follows from known mechanical laws; and the subsequent breaking up of each zone, and the consolidation of its fragments into a planet, are processes which similarly involve none but established dynamical principles. It equally follows, from elementary laws of mechanics, that the planets thus formed would revolve and rotate both in the directions and in the planes in which they are actually observed to revolve and to rotate. There is thus, observes Mr. Mill, nothing gratuitous in Laplace's speculation: "it is an example of legitimate reasoning from a present effect to a possible past cause, according to the known laws of that cause."

But the evidence in favour of the theory of nebular genesis is not restricted to these general coincidences between observation and deduction. Many striking minor details in the structure of the solar system, otherwise apparently inexplicable, are beautifully explained by the theory of nebular genesis. Let us first consider a case which would appear to be an obstacle, not only to this, but to any other framable theory. We have already hinted that Uranus, while revolving in the same direction with the other planets, has a backward rotation, so that to an observer placed upon Uranus the sun would seem to rise in the west and set in the east. His moons revolve about him in the same retrograde direction ; and his axis, instead of standing at a great angle to his orbit-plane, as is the case with all the nearer planets, lies down almost upon the orbit-plane. It has been asserted that these peculiarities are also manifested by Neptune — though our opportunities for observing the latter planet are so few that this point cannot yet be regarded as well established. Why now should such exceptional phenomena be manifested in the case of either or both of these outermost planets? In his essay on the Nebular Hypothesis, Mr. Spencer has shown that these phenomena may be explained by a reference to the shape of the rings from which the outermost planets were formed. When the solar nebula was so large as to fill the orbit of Neptune, its rotation must have been slower, and its figure consequently less oblate, than at later stages of contraction. Now the ring detached from a very oblate spheroid, which bulges greatly at the equator, must obviously be shaped like a flat quoit, as is the case with Saturn's rings; while conversely the ring detached from a spheroid which bulges comparatively little at the equator, will approximate to the shape of a hoop. Hence the rings which gave rise to Neptune and Uranus, having been detached before the solar nebula had attained the maximum of oblateness, are likely to have been hoop-shaped; and when we consider the enormous circumferences occupied by these rings, compared with the moderate sizes of the resulting planets, we see that they must have been very thin hoops. Now in such a hoop the angular velocities of the inner and outer surfaces respectively will be nearly equal, and the planetary mass into which such a hoop concentrates will have its greatest diameter at right angles (or nearly so) to the plane of its orbit; so that its tendency to rotate in the line of its revolution will be so slight as to be easily overcome by any one of a hundred possible disturbing circumstances. Without feeling required to point out the precise nature of such circumstances, we may readily see that, in the case of the outermost planets, the causes which ordinarily make the rotation coincide with the line of revolution were at their minimum of efficiency. So that this retrograde rotation of Uranus, though not perhaps actually implied by the hooped shape of its ancestral ring, is at any rate quite in accordance with it.

I cite this example, not merely on its own account, but also by reason of the further disclosures to which it leads us. Whatever may be thought of the special interpretation just cited, there is no doubt that Mr. Spencer's conception of hoop-shaped and quoit-shaped rings points to a notable series of harmonies among the phenomena of the solar system. Observe, first, that according to the theory, the outer planets ought in general to be much larger than the inner planets; and for a very simple reason. The ancestral rings which coincided with the immense orbits of Uranus and Neptune must of course have been larger than the ancestral rings which coincided with the smaller orbits of Mars and the earth. A ring, for example, which is seventeen thousand millions of miles in circumference may be expected to contain more matter than a ring which is less than six hundred millions of miles in circumference; and hence we may understand why Neptune contains at least sixteen times as much matter as the earth.

But this, though significant, is not a complete explanation; for as the case now stands it would seem as if there ought to be a regular gradation in the sizes of the planets. Not only ought

Mercury to be the smallest, but Neptune ought to be the largest. The facts, however, do not accord with this view. The four outer planets are indeed much larger than the four inner ones. But of the inner group the largest is not Mars, but the earth ; while in the outer group we find Jupiter three and a half times as large as Saturn, which in turn is seven times larger than Uranus. Now the key to these apparent anomalies must, I think, be sought in the shapes of the rings from which the planets were respectively formed. Neptune and Uranus, formed from very thin hoop-like rings, at a period when the solar equator protruded but slightly, are indeed large planets, but not so large as would be inferred from the size of their orbits alone. But as the solar nebula continued to contract, its increasing equatorial velocity rendered it more and more oblate in figure, so that the rings next detached were quoit-shaped. Hence the resulting planets not only had their major diameters but little inclined to their orbit-planes, but they were also larger in size. The very broad quoits which gave rise to Jupiter and Saturn may well have contained more than fourteen times as much planetary matter as the extensive but slender hoops which formed the two oldest planets. If, instead of looking at the sizes of the resulting planets, we consider the thicknesses of the genetic rings, as determined by comparing the size of a planet with the size of its orbit, we shall see that, from Neptune to Jupiter, there was a regular increase in the thickness of the rings, such as the theory might lead us to anticipate.

But now after the separation of Jupiter from the parent mass, we encounter a break in this series of phenomena. The thickness of the detached rings sinks to a minimum in the case of the asteroids, and then steadily increases again till in Mercury there is once more an approach to the quoit shape. Observe the curious sequence of facts, which hitherto, so far as I know, has never been noticed by any of the writers who have treated of the nebular hypothesis. Since the mass of Mercury is four fifths that of Venus, while the circumference of his orbit is about one half that of the orbit of Venus, it follows that his ancestral ring must have been much thicker than that of Venus. Again, the earth is but little larger than Venus, while the circumference of its orbit exceeds that of the latter nearly in the ratio of five to three, so that it must have originated from a thinner ring. Mars, with an orbit exceeding the earth's in the ratio of eight to five, and containing but one eighth as much planetary matter as the earth, must have been formed from a still thinner ring. And since the asteroids, if all piled together, would not make a planet as large as

Mars,[1] while they move through a very much greater orbit, it follows that their parent-ring must have been the thinnest of all. In marvellous conformity to this general statement, it also happens that the inner planets rotate in planes which diverge more widely from their orbit-planes than in the case of Jupiter and Saturn, though less widely than in the case of Uranus and Neptune.[2] And lastly let us note

[1] It may be objected that we have probably not yet discovered all the asteroids. Those not yet discovered, however, must obviously be so small that the addition of them to the aggregated mass of those already known would not materially affect the truth of my statement.

[2] Curiously enough, if we examine the different systems of satellites, we find a similar general contrast in size between the members of outer and inner groups. The two outer satellites of Jupiter are much larger than the two inner ones; and the same relation holds between the four acknowledged satellites of Uranus; while of the eight Saturnian satellites, the four outer ones seem to be decidedly larger than the four inner ones. Moreover the largest of Jupiter's moons is not the outermost, but the third; and of Saturn's moons the largest is not the eighth, but the sixth. To these interesting facts which Mr. Spencer has pointed out, I will add one which he has not observed. If instead of looking at the sizes of the moons, we consider the thicknesses of their genetic rings, as determined by comparing the size of a moon with the size of its orbit, we find in the Jovian system a regular increase in the thickness of the rings, from the outermost to the innermost. Similar evidence from the Saturnian system is not yet forthcoming, since the masses and even the volumes of Saturn's moons have not yet been determined with sufficient accuracy for this purpose.

that the velocities of the planetary rotations supply further confirmation; for "other things equal, a genetic ring that is broadest in the direction of its plane will produce a mass rotating faster than one that is broadest at right angles to its plane;" and accordingly Jupiter and Saturn, originating from relatively quoit-shaped rings, rotate very swiftly; while all the inner planets, originating from relatively hoop-shaped rings, rotate with much less rapidity.

Here we may profitably consider the singular instance in the history of the solar system in which a detached ring has failed to become integrated into a single planetary mass. Every one remembers how, in accordance with the law of Titius concerning planetary intervals, Kepler was led to predict the existence of a planet between Mars and Jupiter; and how, at the beginning of the present century, not one only, but four such planets, were suddenly discovered. More than a hundred of these little bodies have now been detected, and each year adds new names to the list. The four earliest observed — Vesta, Juno, Ceres, and Pallas — are of respect-

And concerning the Uranian system our knowledge is still more inadequate. It will be observed, however, that even the facts here fragmentarily collated point clearly to some common mode of genesis for both planets and satellites; and are likely, when completely generalized, to yield important testimony in behalf of the nebular theory.

able dimensions; Pallas having a diameter of 600 miles, or more than one fourth the diameter of our moon. Most of the others are quite tiny, the smallest having a surface perhaps not larger than the state of Rhode Island. Not only do they occupy the position which would normally belong to a single planet between Mars and Jupiter, but it is hardly questionable that they have all originated from a single ring; for their orbits are interlaced in such a complicated way that, if they were material rings instead of ideal lines in space, it would be possible to lift them all up by lifting any one of them. Why should just one of the solar rings have failed to develop into a single planet, and why should such an arrest of development have occurred in just this part of the solar system?

According to Olbers, the discoverer of Pallas and Vesta, this is not a case of arrested development, but these little bodies are merely the fragments of an ancient well-developed planet, which has been in some way exploded. But this hypothesis, though countenanced by Mr. Spencer, seems to me unsatisfactory. In Mr. Spencer's essay, it is closely connected with the hypothesis of a gaseous nucleus for all the planets, which, though there ingeniously elaborated, seems to me as yet too doubtful to serve as a basis for further explanations. And even granting the hypothesis, it would be necessary further to show why in this planet alone the outward pressure of the gaseous nucleus should have overcome the resistance of the solidified crust. I believe that the problem is much nearer a solution when we treat it as a case of arrested development; for on this view the peculiar fate of the ancestral ring may be at least partially explained by a reference to the perturbing attraction exerted upon it by Jupiter.

When we reflect upon the immensity of the distances which separate the outer planets from each other, even in conjunction, we perceive that during the earlier stages of nebular contraction no planet was in danger of being disturbed in its formation by the attraction of its next outer neighbour and predecessor. But as the increasing equatorial protuberance of the solar spheroid began to result in the formation of larger and larger planets, and as the formation of planets began, according to the law of Titius, to occur at shorter and shorter intervals, there began to be some danger of such disturbance. There was no chance for a catastrophe, however, until the time when the asteroid-ring was detached. The enormous Jupiter-ring was at least 370,000,000 miles removed from Saturn, besides which its huge mass, implying powerful gravitative force among its constituent parts, served further to ensure its equilibrium. Hence it ran little risk of incurring disaster in the course of its planetary development. It was otherwise with the ancestral ring of the asteroids. This thinnest and weakest of rings started on its independent career at a distance of only 240,000,000 miles from Jupiter — the planet whose gravitative force is more than twice that of all the other planets put together. Under such circumstances it would seem impossible that a planet could be formed. The asteroid ring must have been liable to rupture, not only from the causes which affect all planet-forming rings alike, but also from the strain exerted upon it, now in one part and now in another, by Jupiter's attraction. The fragments of a ring, torn asunder by such a cause, would not continue to occupy the same orbit — they would be dragged from the common path in various directions and to various distances, according to the ever-changing position of the disturbing body. Henceforward, instead of chasing directly on each other's heels, they would rush along in eccentric, continually intersecting paths, and there would thus be no opportunity for consolidation, except in the case of two fragments meeting each other at the intersection of their orbits. As a final result we should have, not one good-sized planet, but a multitude of tiny planets, with intersecting orbits exhibiting great differences in eccentricity. All this is true of the group of asteroids. While the mean breadth of the ideal zone occupied by their orbits is about 100,000,000 miles, its extreme breadth reaches 250,000,000 miles. While the orbit of Europa is more nearly circular than any of the orbits of the true planets, on the other hand the orbit of Polyhymnia attains an almost cometary eccentricity, the difference between its perihelion and aphelion being nearly 200,000,000 miles.

There is one other circumstance, however, which my hypothesis thus far fails to explain. While the true planets revolve in planes but slightly inclined to the ecliptic — the orbit of Mercury showing an inclination of about seven degrees as the maximum instance — the asteroids, on the contrary, revolve in planes of quite various degrees of inclination, the orbit of Pallas rising above the ecliptic at an angle of thirty-four degrees. As the disturbing attraction of Jupiter, however various in direction, would seem to have been exerted wholly in one plane, I am unable to account for this diversity of inclinations. Yet in spite of this shortcoming in the hypothesis — which might perhaps be removed by some one more thoroughly conversant with dynamics — all the other circumstances in the case point unmistakably to the forcible rupture of the genetic ring by the attraction exerted by Jupiter; and thus it would seem that, just when such an untoward event in the history of the solar system might have been expected to occur, it did occur.

Supposing this explanation to be sound in principle, it is quite easy to show why such an event has not occurred subsequently. The next ring — the one which gave rise to Mars — must have been more than twice as thick as the genetic ring of the asteroids, and consequently better fitted to resist a strain from without. And, moreover, being 115,000,000 miles farther removed from Jupiter, the latter planet could exert upon it only four ninths of the disturbing force which it had exerted upon the asteroid-ring. Thus the Mars-ring was permitted to develop into a planet. In turn, the small size of Mars prevented him from exerting any disastrous perturbing force upon the ring which gave rise to the earth, though his distance from that ring could not have exceeded 50,000,000 miles. A simple computation will show that Mars could exert upon the earth-ring not much more than one hundredth part of the attraction exercised by Jupiter upon the ancestral ring of the asteroids. On the other hand, had the mass of Mars been one twenty-fifth as great as that of Jupiter — that is, thirteen times as great as the mass of the earth — he might have prevented the formation of the planet on which we live. And had the mass of Mars been equal to that of Jupiter, he might have dealt destruction to all the planetary rings subsequently detached between himself and the present solar surface. The earth, Venus, and Mercury would in such a case have been represented by a triple zone of asteroids, revolving in more or less eccentric orbits, and the portions of planetary matter which constitute the German armies beleaguering Paris might to-day[1] have been peacefully whirling in space, ten million miles removed from the portions which constitute the starving population of that unhappy city.

Joining together all the foregoing considerations, we have a most interesting array of facts, which I believe have not hitherto been contemplated in connection with one another. Though in the sizes of the planets, superficially regarded, we find no conspicuous symmetry of arrangement, yet in the thickness of the genetic rings, as obtained by a legitimate process of inference, we find a symmetry of disposition that is striking and suggestive. From Neptune to Jupiter we find a progressive increase in thickness that is entirely in conformity with the nebular hypothesis. From the asteroids to Mercury there is a similar progressive increase which is similarly in entire harmony with the hypothesis. And in the only group of satellites concerning which we have adequate data, there is observed

[1] That is, in December, 1870.

a parallel phenomenon. But in the solar system there is a conspicuous break in the uniformity of succession; and this break curiously occurs just at the place where, according to the most plausible supposition, there was an arrest or failure in the normal formation of a planet. I have partially succeeded in tracing this arrest or failure to the immediate effects wrought by the mere proximity and gigantic size of the planet just preceding in the order of detachment. Whether it can be shown that this cause, which well-nigh accounts for one of this group of phenomena, will account in some analogous way for the whole group — whether it can be shown that the detachment of this gigantic mass may have altered the dynamic relations of the central spheroid in such a way as to reduce to a minimum its power of eliminating further rings, I will not pretend to say. It seems to me better to leave the problem with this clear and definite statement, rather than to encumber it with hypothetical explanations which are quite likely to prove purely gratuitous. Of the various explanations which have occurred to me, none seem at all satisfactory; and I will gladly resign, into abler hands, the task of solving the problem. What we may regard, however, as fairly established, is this, — that while, after the formation of Jupiter, the detachment of rings followed the same law of progression as before, there was nevertheless some newly introduced circumstance present which affected the whole series of detachments in common. But while the non-explanation of this newly introduced circumstance leaves a serious gap in the argument, it is to be noted that all the facts, so far as collated, are in harmony with the nebular hypothesis, — the existence of the zone of asteroids, in particular, furnishing powerful evidence in its favour.

If we pass from this complicated problem to the much simpler one of the distribution of the satellites, we shall find evidence in behalf of nebular genesis so remarkable as almost to amount to demonstration. Whoever has read the favourite speculations of theologians concerning the "plurality of worlds" will doubtless remember how strikingly the divine goodness is illustrated in the law that in general the remoter planets have the greater number of satellites. Here, however, as in so many cases, observes Mr. Proctor, "the scheme of the Creator is not so obvious to human reasoning as some have complacently supposed." The "contrivances" for lighting Saturn are by no means what they ought to be, according to this teleological hypothesis. The illuminating power of our moon is (from its greater proximity to the sun) sixteen times greater than that of all the eight moons of Saturn combined; while if that planet were habitable, his rings would prove a formidable nuisance. Mr. Proctor has shown that, in latitudes corresponding to that of New York and Naples, they cause total eclipses of the sun, which last seven terrestrial years at a time. But the problem which natural theology thus fails to solve is completely solved by a very simple mechanical consideration. Since the detachment of a moon-forming ring from a contracting planet depends on the excess of centrifugal force over gravity at its equator, it is evident that rings will be detached in greatest numbers from those planets in which the centrifugal force bears the highest ratio to gravitation. Such planets will have the greatest number of moons. And such, in fact, is the case. Of the four inner planets, which rotate slowly, and in which the centrifugal force is therefore small, only the earth is known to have a satellite.[1] But Jupiter, whose centrifugal force is twenty times greater than that of any of the inner planets, has four satellites. Uranus, with still greater centrifugal force, has at least four, and probably six or eight moons. And finally Saturn, in which the centrifugal force is one sixth of grav-

[1] It is not improbable that Venus may have a satellite also. Several astronomers have declared that they have seen such a satellite; but as their testimony seems difficult to reconcile with that of other astronomers, equally competent as observers, the question must remain an open one for the present.

ity, being nearly fifty times greater than on the earth, has at least eight moons, besides his three unbroken (or partly broken) rings. Mr. Spencer may well declare that this emphatic agreement of observation with deduction is an unanswerable argument in favour of the nebular theory. Here, where the dynamic relations involved are so simple that we have no difficulty in tracing them, the significance of the result is unmistakable. Where we are enabled thus directly to put the question to Nature, there is no ambiguity in her answer.

In the quoit-shaped rings which girdle Saturn, we have a curious vestige — upon the significance of which Kant strongly insisted — of the ancient history of our planetary system. So great has been the centrifugal force upon Saturn, due to his rapid rotation and small specific gravity, that the detachment of rings would seem to have gone on after the surface of the planet had assumed the liquid state; and whether the rings thus formed be now continuous, or (as is far more probable) discontinuous, they have obviously had a much better chance of preserving their equilibrium than the ordinary vaporous moon-forming rings. The dynamics of the Saturnian system still present many difficult questions; but the fact that Saturn is the one planet which is still girdled by rings that are apparently continuous is a very powerful argument in favour of the nebular hypothesis.

But the evidence does not end with these mechanical illustrations. In the present physical condition of the various planets, so far as it can be determined, we shall find further corroborative testimony. It is a corollary from the nebular hypothesis that all the planets, having successively originated from the same vaporous mass, must be composed in the main of similar chemical elements; and this inference has thus far been uniformly corroborated by spectroscopic observation wherever there has been an opportunity to employ it. Hence it follows that the process through which the earth has passed in contracting to its present dimensions has been, or will be, repeated to a certain extent upon all the other planets. Upon any planet there must eventually occur a solidification of the crust, an extensive evaporation and precipitation of water, an upheaval of mountains, an excavation of river-beds, and a deposit of alluvium, resulting in sedimentary strata. But obviously the time at which these phenomena occur must depend, not merely upon the antiquity of the planet, but also upon the rate with which it parts with the heat generated during its contraction. Since the outer planets are so much older than the inner ones, it might at first be supposed that they must have progressed much further in consolidation. But against this must be offset the consideration that the ratio of volume to mass is likely to have been from the first very much greater in the case of the earlier planets than in the case of the interior ones, since formed from a denser sun. Even now the high ratio of volume to mass is one of the most striking characteristics of the four outer as compared with the four inner planets; and as bulky bodies radiate heat much more slowly than small ones, it may well be that this relatively small density indicates the retention of a relatively great amount of molecular motion. Of all the factors in the case, bulk is undoubtedly the most important. Just as the hot water in the boiler may remain warm through a winter's night, while the hot water in the tea-kettle cools off in an hour, so a great planet like Jupiter may remain in a liquid molten condition long after a small planet like the earth, though formed ages later, has acquired a thick solid crust and a cool temperature. Hence in a general survey of the solar system we may expect to find the largest planets still showing signs of a heat like that which formerly kept the earth molten, and we may expect to find the smallest planets in some cases showing signs of a cold more intense than any which has been known upon the earth.

Now this series of inferences, constituting simply an elaborate corollary from the theory of nebular genesis, is fully confirmed by observation in the cases of Saturn, Jupiter, Mars, and the Moon, — the only planets whose surfaces have been studied with any considerable success. According to the nebular hypothesis, Jupiter and Saturn ought to be prodigiously hot; and so they appear to be when carefully examined. The tremendous atmospheric disturbances observed upon both these planets are such as cannot well be explained by the comparatively sluggish action of the sun's radiance upon such distant orbs. The atmosphere of Jupiter is laden with masses of cloud, whether composed solely of water or not, whose cubic contents far exceed those of all the oceans on the earth. The trade-winds, due to the swift rotation of the planet, gather these enormous masses into belts parallel with its equator. Storms and typhoons are incessantly raging in this vapour-laden atmosphere; and the forces at work there are so stupendous that dense cloud-belts, thousands of miles in width, are often formed in a single hour. This state of things is not like that which is now witnessed upon the earth's surface; it is more like the state of things observed upon the sun, where tornadoes continually occur, in which the earth, if it were there, would be whirled along like a leaf in an equinoctial gale. A similar state of things must have existed, in miniature, upon our own planet, in that primitive age when its oceans were in large part held suspended in the dense seething atmosphere, and when the intense volcanic fires within kept the surface in ceaseless agitation. In Saturn similar phenomena are witnessed. The appearance called the "square-shouldered figure" of Saturn, first observed by Sir William Herschel in 1805, has suggested the conclusion that the giant bulk of the planet "is subject to throes of so tremendous a nature as to upheave whole zones of his surface five or six hundred miles above their ordinary level." Whether this be really the case, — or whether, as Mr. Proctor more plausibly suggests, the prominences which give the square-shouldered aspect are due to the shoving up of immense masses of cloud far above the mean layer of Saturn's cloud-envelope, — we must equally recognize the presence of intense heat and furious volcanic action in the interior of that planet. When we add that recent calculations have made it almost certain that both Jupiter and Saturn are to some extent self-luminous, it becomes probable that these great planets still resemble their parent, the sun, more closely than they resemble their younger and smaller brethren.

Very different is the state of things witnessed upon the moon. The absence of an atmosphere from the lunar surface was long since proved by the fact that "when stars are occulted by the moon, they disappear instantaneously,"—which would not be the case had the moon an appreciable atmosphere; and spectroscopic evidence has confirmed this conclusion. Nor are there any signs of the presence of liquid oceans, or of running water. Yet if the moon was originally formed from an equatorial zone of the earth, it would seem that it ought to contain the same materials which have from the oldest times constituted a considerable part of the terrestrial surface. Besides this, the vast plains on the moon which the old astronomers supposed to be seas, and named as such, are now held to be areas underlaid by sedimentary rocks implying the former presence of water.[1] If this view be correct, there must in all probability have been winds to excite the erosive movements of the water which caused this sedimentation. For tidal action upon the moon cannot be regarded as a considerable factor in the erosion, unless we go back to that enormously remote period when the earth's tidal pull was still employed in dragging the moon's rotation into synchrony with its revolution.

[1] Moreover, "it is not to be forgotten that, so far as terrestrial experience is concerned, water is absolutely essential to the occurrence of volcanic action." Proctor, *The Moon*, p. 353.

Here there is an apparent discrepancy, which will disappear, however, when we inquire further into the past career of the moon as indicated by the present condition of its surface. To a great extent the lunar surface is made up of huge masses of igneous rock, through which at short intervals yawn enormous volcanic craters, whose fires seem to be totally extinguished. The giant forces required to bring about such a state of things are now quiescent. And this implies that the moon is a dead planet. It implies that the thermal energies which were once instrumental in raising those huge cones, Tycho, Copernicus, and the rest,—quaintly named after our terrestrial heroes of science,—and which once drove up fiery streams of molten lava through their ample mouths, are now clean gone, radiated off into space. This cessation of volcanic activity indicates that the planet has reached its limit of consolidation, and is no longer generating heat from within.[1] Now the degree of cold implied

[1] "Nevertheless, there are processes at work out yonder which must be as active, one cannot but believe, as any of those which affect our earth. In each lunation, the moon's surface undergoes changes of temperature which should suffice to disintegrate large portions of her surface, and with time to crumble her loftiest mountains into shapeless heaps. In the long lunar night of fourteen days, a cold far exceeding the intensest ever produced in terrestrial experiments must exist over the whole of the unilluminated hemisphere; and under the influence of this cold all the substances composing the moon's

by this stoppage of further lunar consolidation must immeasurably exceed anything within terrestrial experience. It may well have been great enough to freeze all the lunar oceans, and even to liquefy, or perhaps to solidify, the gases of

crust must shrink to their least dimensions — not all equally (in this we find a circumstance increasing the energy of the disintegrating forces), but each according to the quality which our physicists denominate the coefficient of expansion. Then comes on the long lunar day, at first dissipating the intense cold, then gradually raising the substance of the lunar crust to a higher and higher degree of heat, until (if the inferences of our most skilful physicists, and the evidence obtained from our most powerful means of experiment can be trusted) the surface of the moon burns (one may almost say) with a heat of some 500° F. Under this tremendous heat all the substances which had shrunk to their least dimensions must expand according to their various degrees ; not greatly, indeed, so far as any small quantity of matter is affected, but to an important amount when large areas of the moon's surface are considered. Remembering the effects which take place on our earth, in the mere change from the frost of winter to the moderate warmth of early spring, it is difficult to conceive that such remarkable contraction and expansion can take place in a surface presumably less coherent than the relatively moist and plastic substances comprising the terrestrial crust, without gradually effecting the demolition of the steeper lunar elevations. When we consider, further, that these processes are repeated not year by year, but month by month, and that all the circumstances attending them are calculated to render them most effective because so slow, steadfast, and uniform in their progression, it certainly does not seem wonderful that our telescopists should from time to time recognize signs of change in the moon's face." Proctor, *The Moon*, pp. 380–382.

the lunar atmosphere. The moon is indeed subjected at each rotation to the fierce noontide heat sent from the sun; but however this may scorch and blister the rocky surface, it can exercise but little melting power. An atmosphere, as Mayer has happily observed, is like a valve which lets water run through in one direction, but not in the other. Through an enveloping atmosphere the solar rays easily pierce, but return with difficulty. But from the airless surface of the moon the solar radiance must be immediately reflected into space, as from the surface of a polished mirror. Just as on the summits of the Himalayas, where the atmosphere is so rare, the huge snow masses remain through centuries unmelted, in spite of the sun's blazing heat; so on the surface or in the deep abysms of the moon, the air and water once frozen must remain frozen forever.

We have not yet, however, reached a satisfactory interpretation of the original disappearance of the lunar atmosphere. Granting the disappearance of the atmosphere, the maintenance of a more than arctic cold in spite of the utmost intensity of solar radiation may readily be admitted. But in this explanation the absence of a surface atmosphere is presupposed rather than accounted for. Yet I have thought it worth while to introduce the case in this way, as we thus get a more vivid impression of the actual state of things upon the moon. For the original disappearance of the lunar air and water, a far more thoroughgoing explanation was propounded some years since by M. Saemann;[1] but in this explanation the extreme cooling of the moon, as just illustrated, is implicitly involved. According to M. Saemann's essay, the lunar air and water have been literally *drunk up* by the thirsty rocks. On our own globe the tendency of the surface-water is constantly to percolate through the soil of the land or sea-bottom, and thence through the rocks, downward towards the centre of the earth. Yet with our present supply of internal heat, it is not probable that any water can reach more than one hundredth part of the distance towards the earth's centre, without becoming vaporized and thus getting driven back towards the surface. In this way there is kept up a circulation of water through the peripheral portions of the earth's crust. But as the earth becomes cooler and cooler, the water will be enabled to circulate at greater and greater depths, thus materially lowering the level of the ocean. In this way, long before the centre has become cool, all the surface-water of the earth will have been sucked into the pores of the rocks, and a similar pro-

[1] In a paper on the unity of geological phenomena throughout the solar system, translated by Professor Sterry Hunt, and published in the *American Journal of Science*, January, 1862.

cess will afterwards take place with the atmosphere. M. Saemann shows that by the time the earth had reached complete refrigeration, the pores of the rocks would absorb more than one hundred times the amount of all the oceans on the globe, while room would still be left for the retiring atmosphere. Now this state of things, which will no doubt by and by be realized on the earth, would seem to be already realized on the moon. Being forty-nine times smaller than the earth, the moon has cooled with great rapidity, and its geologic epochs have been correspondingly short.[1]

After the moon, we are more familiar with the surface of Mars than with that of any other heavenly body, the position of Venus being very unfavourable for thorough observations. Concerning the physical geography and meteorology of Mars, some trustworthy information has been obtained. The distribution of land and sea over his surface is sufficiently obvious to be delineated in maps. He possesses liquid oceans, proved by spectroscopic evidence to consist of water, and his atmosphere is gaseous. That he

[1] It should be added that the rapid cooling of the moon would greatly increase the porosity of its substance. Professor Frankland has shown that "assuming the solid mass of the moon to contract on cooling at the same rate as granite, its refrigeration through only 180° F. would create cellular space equal to nearly fourteen and a half millions of cubic miles."

possesses climates analogous to our own might be inferred from the inclination of his axis to his orbit-plane, and is inductively proved by the fact that we can actually see his polar snows accumulate during the Martial winter and melt away at the approach of the Martial summer. Coincidences like these bear sufficient testimony to a general resemblance between Mars and the earth. For where there are oceans and clouds and an atmosphere and polar snows, there must also be currents, aerial and oceanic, as well as rains, rivers, and sedimentary rocks; so that the surface of Mars must probably present geologic phenomena not essentially unlike those witnessed upon the earth. Whether such geologic similarity has entailed a further resemblance in the case of organic and super-organic phenomena, must be left for the more profound deductive science of some future day to determine.

Thus from whatever point of view we study our planetary system, we find such a congeries of phenomena as would have been produced by the gradual development of the system from a homogeneous nebula. On summing up the conspicuous facts already cited, we see that the nebular hypothesis fully explains the shapes of the planetary orbits, and their slight inclinations to the plane of the solar equator; the shapes of the satellite-orbits, and their proximate coincidence with the equatorial planes of their primaries; the inclinations of the planetary axes to their orbit-planes; the oblate figures of the planets; their velocities of rotation; the directions in which they revolve; and the directions in which they rotate. To this last clause the apparent obstacle presented by the retrograde rotation of Uranus (and possibly of Neptune also) is seen on closer examination to be no real obstacle; and the fact that the exception occurs among the outermost planets, just where we might expect it to occur, if at all, is a powerful argument in favour of the general theory. A like powerful argument is furnished by the existence of apparently continuous rings about Saturn, the planet upon which the centrifugal force bears the highest ratio to gravity. Still more convincing is the testimony rendered by the distribution of satellites, — a testimony well-nigh meeting all the requirements of crucial proof. Irregular as are the sizes of the planets on a superficial view, we find beneath this apparent irregularity a marvellous symmetry of disposition, the explanation of which, though incomplete, is as far as it goes in favour of the nebular hypothesis. The breaking up of the zone of asteroids, though not fully explained, is seen to have occurred in the only part of the system where such an event, according to the hypothesis, was likely to occur. And finally the geologic or meteorologic phenomena manifested by the four planets whose surfaces have thus far been successfully studied are just what the theory requires them to be. The intense heat and furious volcanic activity of Jupiter and Saturn, the extreme loss of heat and cessation of volcanic activity upon the moon, the moderate temperature and habitable aspect of Mars, are alike deducible from the nebular hypothesis.

I doubt if such persistent agreement between deduction and observation has ever been witnessed in the case of an erroneous or radically inadequate hypothesis. If the sole ultimate test of a theory is that it reconciles the order of conceptions with the order of phenomena, may we not say that the theory of Kant and Laplace, having sustained the repeated application of this test, may be accepted provisionally as a true account of the past history of our system of worlds? It is true that the application of the test has not yet been made exhaustive; the verification is not yet complete. Some of the interpretations above given are still, as I have acknowledged, but partial; and there are yet other groups of phenomena with which I have not ventured to meddle. To the various densities of the planets I have alluded but incidentally; and the various angular velocities, as well as the order of distances formulated in the law of Titius, still await an explanation. Besides which, the evidence from the physical condition of the surfaces of Mercury and Venus, Uranus and Neptune, and the moons of the four outer planets, is not yet forthcoming. It would be asserting too much, therefore, to assert that the nebular hypothesis is completely verified, like the hypothesis of gravitation. But on the other hand, they understand little of the logic of scientific inquiry who expect to obtain the same kind and degree of evidence in the former case as in the latter. It was part of Newton's rare good fortune that his hypothesis was the generalization of a physical property of matter, which could be verified by a single crucial instance. In none of the concrete sciences can such kind of verification be looked for. A theory relating to a heterogeneous assemblage of concrete phenomena can only be verified gradually, as the successive groups of phenomena in question are one after another successfully studied and interpreted. Thus the complete verification of the nebular hypothesis, as applied merely to the solar system, involves the complete explanation of the chief dynamic and physical features of the system; and for this we have yet to wait. Meanwhile the theory possesses such unmistakable marks of genuineness, it conforms in so many and various ways to the test of reconciling the order of conceptions with the order of phenomena, that no one capable of estimating scientific evidence would hesitate in provisionally accepting it. Devised to account for a certain limited group of phenomena, it not only accounts for these, but also for other groups of phenomena, not considered by its propounders. Facts which on a superficial view appeared as obstacles to the theory have on closer examination turned out to be powerful arguments in its favour. It is sustained by all the facts within our ken, and invalidated by none. And it has so far thriven with the progress of discovery during the past hundred and twenty years, that at the present moment it commands wider assent than at any previous time since its first promulgation.

Of this last statement we find striking confirmation as we pass beyond the limits of the solar system and seek for evidence in the remotest depths of stellar space. It is well known that Sir William Herschel supposed certain irresolvable nebulæ to consist of self-luminous vapour hovering cloud-like in space. Laplace associated this hypothesis with his own theory of planetary evolution ; pointing to the present existence of nebulous masses as confirmatory proof of the past existence of such a nebulous mass as his theory required. According to this view, the irresolvable nebulæ are simply starry systems in embryo; and when our planetary system consisted simply of the sun diffused in gaseous form over a circumference of perhaps thirty thousand million miles, it was just like one of these nebulæ. But since Herschel's time many nebulæ, which he regarded as irresolvable, have been resolved into dense starry clusters. The great nebula in Orion, upon which Herschel placed great reliance, was resolved both by Lord Rosse's reflector and by our Harvard refractor; and the suspicion began accordingly to arise that, if our telescopes were only powerful enough, there might prove to be no irresolvable nebulæ at all. Hence many writers thoughtlessly hastened to proclaim that the nebular theory had lost its chief support, forgetting that the overwhelming evidence furnished by the comparatively well-known structure of the solar system must take precedence of any hypothesis as to the character of remote and less-known sidereal phenomena. Mr. Chambers, in giving an account of the resolution of the "dumb-bell" nebula in Vulpecula, rather gleefully wrote the obituary of the nebular hypothesis; but like many other obituaries, this one turned out to be premature. For now came Mr. Huggins, with his spectroscope, and proved once for all that the wary and sagacious Herschel, who hardly ever made a false step, was right, here as elsewhere. In 1864 Mr. Huggins analyzed the light sent from a nebula in Draco, and found it to contain the bright lines which are sure evidence of the gaseous condition of the luminous body. Since then several other nebulæ have been proved to be gaseous; so that the question may now be regarded as settled forever, and as settled in favour of the nebular hypothesis. Henceforth, to the evidence found in the structure of our planetary system, there may be added the weighty argument that masses of matter still exist in space, in the very condition in which our system must have originally existed.

If the nebular hypothesis was ever to be subjected to a hazardous trial, one would suppose that the discovery of spectrum analysis must have furnished the occasion. Here is a discovery which has suddenly enlarged our knowledge of the stellar universe in a manner utterly beyond the power of the greatest and subtlest mind to have predicted twenty years ago,— a discovery which not only reveals to us the actual motions of the stars, but even penetrates into their molecular structure, and discloses the chemical elements of which their surfaces are composed as well as the physical state of aggregation of those surfaces. Now if ever, one might think, is the time to find out whether our nebular hypothesis, devised in an era of comparatively scanty astronomical knowledge, is a sound hypothesis or not. If it survives this immense, unprecedented extension of our knowledge, what more magnificent triumph could we wish for it? And here we see that the very first result of the application of spectrum analysis to sidereal phenomena has been the placing of the nebular hypothesis upon a firmer basis than ever before, removing the only serious obstacle which had hitherto deterred many cautious thinkers from committing themselves to it.

Spectroscopic researches but lately undertaken, and not yet carried out to a decisive result, seem likely not only further to strengthen the noble theory of Kant and Laplace, but to give it a comprehensive significance of which those great thinkers could never have dreamed. Along with further confirmation of the process of mechanical and physical evolution, as originally formulated in their hypothesis, evidences are daily coming in to show that there is going on a parallel process of chemical evolution from homogeneity to heterogeneity, which is no less wonderful in its significance. The old empirical classification of stars according to their colours is beginning to have a new meaning. The method of comparison is becoming applicable in astronomy, as it has long been employed in the study of organisms, of societies, and of languages. It begins to be probable that among the various groups of stellar bodies there may be found cosmical matter in many different stages of evolution, — from the primitive nebula which yields but a simple hydrogen-line, to such a highly evolved body as our own sun with the many lined vapour of iron abundant in its heated atmosphere. But into this fascinating region of speculation it would be somewhat premature for us now to enter. Merely indicating what a rich harvest of discovery is here likely to reward the labourers of the immediate future, I would call attention to an interesting speculation of Mr. Spencer's, the possible inadequacy of which need not weaken the effect of the evidence above cited from planetary phenomena, and which is in every way worthy of serious consideration.

According to Mr. Spencer, the distribution of nebulæ affords a significant illustration of the nebular hypothesis. Speaking generally, nebulæ occur in regions where developed stars are scarce. The vast groups of spherical nebulæ, here and there partly developed into starry clusters, which constitute the so-called Magellanic Clouds, are situated in a district of the sky that is otherwise starless. Now by far the most striking of this class of facts is one which serves to bring the entire sidereal system into direct comparison with that little portion of it to which we belong. Just as the planets lie almost entirely in a single plane, so the stars are distributed in almost infinite numbers in the plane of the Milky Way, while elsewhere they occur rarely. And just as the comets are chiefly distributed about the poles of our solar system, their orbits cutting its equatorial plane at great angles, so the nebulæ are found in greatest numbers about the poles of the galaxy. It seems unlikely that this parallelism, which Mr. Spencer was the first to point out, should be accidental. It indicates a common mode of evolution of the whole starry system. It vaguely points to a gigantic process of concentration going on throughout the galaxy, analogous to the local process of concentration which has gone on in our own little planetary group. Still more obvious will this become when we consider the explanation of these phenomena which Mr. Spencer has offered.

Observation shows that while the more consolidated nebulæ are oval or spheroidal in shape, the less consolidated nebulæ are often extremely irregular, throwing out long arms of vaporous matter into the adjacent spaces. This agrees with what we have learned to expect in any rotating mass which gravitation is slowly drawing closer and closer together. The oval form is due, as we have seen, to the combined effects of gravitation and rotatory movement. But this implies an earlier state in which the figure was irregular. Now while the heavier portions of the mass were being drawn together so as to acquire a spheroidal contour, the lighter portions, floating farther from the centre of gravity, would remain like detached shreds of cloud, or like long luminous streaks. And while all these would ultimately be compelled by gravitation to revolve about the centre of the mass, nevertheless the lightest and outermost shreds would be a long time in acquiring a definite direction of revolution. While the greater number would be doubtless drawn in and absorbed by the main mass at an early stage, the chances are that some would not arrive until the main mass had become considerably contracted. Now it is easy to see that such late arriving flocculi, coming toward the centre of gravity from a great distance, and therefore having small angular velocities, will move in very eccentric ellipses. In the next place, while they will come from all parts of the space which the mass originally occupied, they will come chiefly from regions remote from the plane in which integration has been most marked, — that is, from the poles of the nebula rather than from its equatorial regions. And thirdly, having failed to accompany the retreating mass of the nebula while it was first acquiring a definite direction of rotation, their own revolutions will be determined chiefly by their irregular shapes, and they will be as likely to be retrograde as direct.

All this is true of comets: they come chiefly from high solar latitudes, along immensely eccentric orbits, and in directions which are indifferently direct or retrograde. And when we add that they are nebulous in constitution, it appears highly probable that they are simply outlying shreds of the nebula from which our planetary system has been developed. As for the irresolvable patches of nebulous matter which are distributed about the poles of the galactic circle, their distance from us is so great that we have not yet ascertained anything trustworthy concerning their motions. But the fact that their position in high galactic latitudes is explicable upon the same general principles which explain the positions of comets, raises a presumption that their relation to the galaxy as a whole may somewhat resemble that which comets bear to the solar system. Between the possible careers of the nebulæ and the comets, there is, however, a mighty difference. The nebula which we see through quadrillions of miles shining by a light of its own must needs be an enormous object — enormous in mass as well as in volume — and its gravitative force must be proportionate to its size. While, therefore, its gradual contraction is likely to be attended by its development into a planetary system, — by a process of integration and differentiation such as we have here described, — on the other hand the comet is an object of inconsiderable mass, though very often of considerable volume. The slight concentration of which it is capable will not produce planetary systems or even asteroids, but only streams of meteors or shooting-stars, such as are now poured down upon the earth and its neighbour planets at the rate of a hundred thousand million each year. The researches of the past ten years have gone far to show that such meteoric streams differ from nebulous comets in no respect save in their greater aggregation; the difference being similar to the difference between a cloud and a shower of raindrops. We are constantly encountering portions of these condensed comets and uniting them with our own planetary substance. And in this way the integration of the outlying portions of our primitive nebula is, at this late day, still going on.

As we pause to survey, in a single comprehensive glance, this gigantic process of Planetary Evolution, in which the integration of matter and concomitant dissipation of molecular motion, kept up during untold millions of ages, has brought about the gradual transformation of a relatively homogeneous, indefinite, and incoherent mass of nebular vapour into a decidedly heterogeneous, definite, and coherent system of worlds; we are at first struck by the peculiarity that the process has apparently long since come to a close in the establishment of a complete moving equilibrium. Habituated as we are to the contemplation of fleeting phenomena, the stars in their courses have become the types of permanence; and the stability of our planetary system has furnished a fruitful theme for the admiring comments of the mathematician and the theologian. In so far as this appearance of eternal stability is well founded, it admirably illustrates the theorem — already cited in our discussion of the rhythm of motion — that wherever the forces in action are few in number and simple in composition, the resulting rhythms will be simple and long-enduring. Nevertheless the processes still going on in our system are such as to forbid the conclusion that this apparently permanent equilibrium is destined really to be permanent. The concentration of matter and concomitant dissipation of molecular motion, which has gone on from the beginning, must still continue to go on until it has reached its limit. That consolidation and accompanying refrigeration which has changed the earth from a nebula into an incandescent star, and from a star into an inhabitable planet, must continue until a state of things is inaugurated for which we must seek a parallel in the present condition of the moon. So, too, the contraction which generates the prodigious quantity of heat daily lost by the sun cannot go on forever without reducing the sun to a solidity incompatible with the further generation of radiant energy.

Thus the moon appears to afford an example of the universal death which in an unimaginably remote future awaits all the members of the solar system. It then becomes an interesting question whether this cosmic death will be succeeded by Dissolution,— that is, by the rediffusion of the matter of which the system is composed, and by the reabsorption of the lost motion or its equivalent. We shall find it difficult to escape the conclusion that such a dissolution must ultimately take place.

If, along with the dissipation of molecular motion already described, the planets are also losing that molar motion to which is due their tangential momentum, this loss of motion must ultimately bring about their reunion with the sun. Upon such a point direct observation can help us but little; but there are two opposing considerations, of a force which none will deny, and based on facts which none can dispute. Two sets of circumstances are struggling for the mastery, — the one set tending to drive the planets farther and farther away from the centre of the system, the other set tending to draw them towards the centre. Let us see which set must prevail in the end.

Hitherto, in all probability, the first set of circumstances has had the advantage. There is little reason to doubt that all the planetary orbits, both primary and secondary, are somewhat larger now than they were originally. This is an indirect consequence of the slow loss of rotatory momentum due to tidal action. The calculation by which Laplace thought he had proved that the terrestrial day had not lengthened since the time of Hipparchos, has been shown by Professor Adams to be vitiated by the inclusion of an erroneous datum; and the theory involved is no longer tenable. It has been proved that the tidal wave which the moon draws twice a day around the earth, in the opposite direction to the terrestrial rotation, acts upon the earth like a brake on a carriage-wheel. Owing to this circumstance, the day is now one eighty-fourth part of a second longer than at the beginning of the Christian era; and it is destined to continue lengthening until in the remote future there will be from three to four hundred hours between sunrise and sunset. But the rotatory momentum thus lost by the earth is not destroyed. In conformity with a well-known principle of dynamics, it is added to the tangential momentum of the moon, and thus lengthens the radius of the moon's orbit. The more slowly our planet rotates, the farther the moon retires from us. A similar relation holds good in the case of the planets and the sun. Not only is it demonstrable *a priori* that the planets must cause tides upon the surface of the sun, but the tides caused by all the primary planets, save Mars, Uranus, and Neptune, have been actually detected by a minute comparison of the variations in the solar spots. These tidal waves are drawn around the sun in the direction opposite to that of his rotation, and must therefore exert a retarding effect. And the rotatory momentum thus stolen from the sun is added, in accordance with a *pro rata* principle of distribution, to the tangential momenta of the various planets concerned in the theft. There can be little doubt, therefore, that all the planetary orbits, both primary and secondary, are steadily enlarging, and that this process must go on until that synchrony between revolution and rotation now witnessed in our moon becomes universal, unless it is previously checked by the cessation of tidal phenomena. As between the earth and moon, for example, the ultimate result of the whole process must be the lengthening of the terrestrial day until it corresponds with a lunar month, so that the earth and moon will move in relation to each other just as if joined together by a rigid rod. This result will actually be realized unless forestalled by the completed refrigeration of the earth, which will put an end to the tidal friction. In like manner the sun's rotation must diminish until equilibrated with the motions of the planets, unless this result is forestalled by the completed refrigeration of the sun. And in all cases, so long as the process goes on, there must be a tendency, however slight, for the planets to recede from the sun.

The action of this set of circumstances, however, though hitherto no doubt predominant, is strictly limited in duration. Sooner or later an equilibration of motions will be reached, and this receding tendency will cease to be manifested. It is quite otherwise with the opposing set of circumstances which we have now to consider. We have now to contemplate a cause which operating from the very outset, and still insidiously operating, will continue to operate long after the process just described has come to an end. Each year's discoveries show more and more conclusively that the interplanetary spaces are filled with matter. The existence of some interplanetary and interstellar matter is indeed a necessary condition for the transmission of light and other forms of radiance. Now wherever a body moves through a material medium, it meets with resistance; it imparts motion to the medium, and loses motion in so doing. If the body is a planet like Jupiter, weighing a couple of septillions of tons, and rushing along at the rate of eight miles per second through an ether far lighter than the air left in an exhausted receiver, the resistance will be inconceivably small, I admit. Still there will be resistance, and long before the end of time this resistance will have eaten up all the immense momentum of the planet. A Hindu, wishing to give expression to his idea of the duration of hell-fire, said that if a gauze veil were to be brushed against the Himalaya mountains once in a hundred million centuries, the time required for thus wearing away the whole rocky range would measure the torments of the wicked. One marvels at such a grandiose imagination; but the realities of science beggar all such attempts at giving tangible shape to infinitude. The resistance of an ethereal medium may work its effects even more slowly than the Hindu's veil, yet in time the effects must surely be wrought. Either the planets are moving in an absolute vacuum — a supposition which is incompatible with the transmission of heat and light — or else the resistance of the medium must tend to diminish their angular velocities.[1]

In the absence of any counteracting agencies — and, after the cessation of the process above described, none such are assignable — this loss of tangential momentum must ultimately bring all the planets into the sun, one after another, beginning with Mercury and ending with Neptune. Here the concentration of matter appears to have reached its limit. But what must now happen?

[1] See Balfour Stewart, in *The Conservation of Energy*, p. 96.

Let us note that the tangential momentum lost by the planet is lost only relatively to its distance from the sun. As the planet draws nearer to the sun, its lost tangential momentum is replaced, and somewhat more than replaced, by the added velocity due to the increased gravitative force exerted by the sun at the shorter distance. But this newly added momentum is all needed to maintain the planet at its new distance from the central mass, and can never be available to carry it back to the old distance. It is thus that Encke's comet moves more and more rapidly as it approaches the sun, into which it appears to be soon destined to be drawn. For these reasons the earth, which now moves at the rate of 18 miles per second, would attain a velocity of 379 miles per second when in the immediate neighbourhood of the solar mass. Hence when at last the planet strikes the sun, it must strike it with tremendous force. In a collision of this sort, the heat generated by the earth and sun alone would suffice to produce a temperature of nearly nine million degrees Fahrenheit. Without pursuing the argument into further detail, it is obvious that the integration of the whole solar system, after this fashion, would be followed by the complete disintegration of the matter of which it is constituted. After the reunion of the planets with the sun, the next stage is the dissipation of the whole mass into a nebula.

If we now go back for a moment to the beginning, and ask what antecedent form of energy could have generated the motion of repulsion which sustained our genetic nebula at its primitive state of expansion, the reply must be that nothing but a rapid evolution of heat could have generated such a motion of repulsion. And if we ask whence came this rapid evolution of heat, we may now fairly surmise that it was due to some previous collision of cosmical bodies; arrested molar motion being incomparably the most prolific known source of heat. Thus we get a glimpse of some preceding epoch of planetary evolution, from the final catastrophe of which emerged the state of things which we now witness.

We have here reached the very limit of scientific inference. For note that, since the greater part of the potential energy represented by the primitive expansion of our solar nebula has been transformed into heat and radiated away, and is not represented by any form of motor energy now stored up in the solar system, it follows that the sudden transformation of the penultimate molar motions of the planets into heat cannot result in the production of another nebula so large as the one from which our present system has been evolved. In seeking to trace out the implications of this conclusion, we at once arrive at an impassable barrier, which is only shifted, but not overthrown, when we consider the results of the probable ultimate conflict between our own system, thus disintegrated, and other sidereal systems belonging to our galaxy. In order to give a complete account of the matter, we ought to know what has become of all this motor energy which we have been so prodigally pouring away, in the shape of radiant heat, into the interstellar spaces. Is the equivalent of this motor energy ever to be restored, or is the greater part of it forever lost in the abysses of infinite space? Before we can answer such a question, we need to know whether the interstellar ether, which is the vehicle for the transmission of molecular motion, is definitely limited in extent, or practically infinite; and we need to take into the account the dynamic relations, not only of our entire galactic system, but of other stellar systems, if such there are, beyond the utmost ken of the telescope. Here science fails us. Astronomy, the simplest and clearest of the sciences, becomes, when treated on this great scale, the most difficult and obscure. An infinity and an eternity confront us, the secrets of which we may not hope to unravel. At the outermost verge to which scientific methods can guide us, we can only catch a vague glimpse of a stupendous rhythmical alternation between eras of Evolution and eras of Dissolution, succeeding each other "without vestiges of a beginning and without prospect of an end."

# CHAPTER VI

## THE EVOLUTION OF THE EARTH[1]

IN treating of Evolution in general, it was shown how organic bodies are, by a peculiar concurrence of conditions, enabled to lock up a great deal of motion within a small compass, so that permanent redistributions of structure and function can be effected. From the decisiveness with which this peculiar advantage possessed by organic bodies was indicated, it might have been surmised that in the case of inorganic aggregates an attempt to trace the secondary phenomena of differentiation and integration would prove illusory, owing to the absence of this concurrence of conditions. In many inorganic bodies it is true that there does not go on to any notable extent that secondary redistribution which results in increase of heterogeneity. The evolution of a cloud, a rock, or a crystal, is little more than an integration of matter attended by dissipation of motion. In the evolution of the solar system, on the other hand, we have witnessed an increase in heterogeneity, definiteness, and coherence that

[1] [See Introduction, § 17.]

is very marked, though by no means so prominent as in the case of organic evolution. This increase in determinate multiformity, such as it is, is due to the special mechanical principle that in any rotating system of particles, regarded as practically isolated, a steady concentration, entailing increased rotatory velocity, must end in the segregation of the equatorial zone from the rest of the system. This principle is exemplified, on a diminutive scale, in the artificial evolution of a system of oil-globules, whereby M. Plateau has imitated the evolution of the planets. To the resulting equilibration between gravity and the centrifugal tendency, at the place where the detachment occurred, is due the permanence and definiteness of the structural differentiation. Owing to these conditions, and to its enormous size, implying great power of condensation along with the very slow dissipation of the heat generated by the condensation, the integration of our genetic nebula has been compatible with the retention of much relative motion of parts. And here accordingly, as in all cases where there is a considerable retention of internal motion, the secondary rearrangements characteristic of Evolution have been conspicuously manifested.

In the evolution of our earth, regarded by itself, we have also to notice a very decided progress in determinate multiformity, even without taking into the account that specialized group of terrestrial phenomena which we distinguish as organic. Here there have been two conditions favourable to the retention of enough motion to allow considerable secondary rearrangement of parts. In the first place the great size of the earth has prevented it from parting too rapidly with the heat generated during its condensation; and since the early formation of a solid, poorly conducting crust, the loss from radiation would seem to have been very gradual. The importance of this circumstance may best be appreciated by remembering the very different career of the moon, as indicated in the foregoing chapter. The disappearance of igneous and aqueous agencies on the moon implies the cessation of structural rearrangement there at this early date;[1] and when we sought for an explanation of this state of things, we found an adequate explanation in the rapid loss of heat which the small size of the moon has entailed. It is not likely, therefore, that the moon can ever have been the theatre of a geologic and organic development so rich and varied as that which the earth has witnessed.[2]

[1] This statement must be taken, however, with some qualification. See above, pp. 284, 285.

[2] An example of the too hasty kind of inference which is often drawn in discussing the question of life upon other planets may be found in a recent lucid and suggestive pamphlet

In the second place, the following chapter will show that the chief circumstance which has favoured terrestrial heterogeneity has been the continuous supply of molecular motion from

by Professor Winchell, entitled "The Geology of the Stars." "The zoic age of the moon," says the author, "was reached while yet our world remained, perhaps, in a glowing condition. Its human period was passing while the eozoön was solitary occupant of our primeval ocean." More careful reflection will probably convince us that, with such a rapid succession of geologic epochs, the moon can hardly have had any human period. For the purposes of comparative geology, the earth and the moon may be regarded as of practically the same antiquity. Now, supposing the earliest ape-like men to have made their appearance on the earth, say during the Miocene epoch, we must remember that at that period the moon must have advanced in refrigeration much farther than the earth. Supposing organic evolution to have gone on with equal pace in the two planets, it might be argued that the moon would be fast becoming unfit for the support of organic life at about the time when man appeared on the earth. Still more, it is a fair inference from the theory of natural selection, that upon a small planet there is likely to be a slower and less rich and varied evolution of life than upon a large planet. On the whole, therefore, it does not seem likely that the moon can ever have given rise to organisms nearly so high in the scale of life as human beings. Long before it could have attained to any such point, its surface is likely to have become uninhabitable by air-breathing organisms. Long before this, no doubt, its surface air and water must have sunk into its interior, and left it the mere lifeless ember that it is. The moon would thus appear to be not merely an extinct world, but a partially aborted world; and the still smaller asteroids are perhaps totally aborted worlds. Nevertheless, from the earth down to the moon, and from the

the sun. To this source may be traced all the aqueous phenomena, save the tides, which concur in maintaining the diversity of the earth's surface. And having thus seen how a complex geologic evolution is rendered possible, we shall further discern that organic evolution also, that highly specialized series of terrestrial events, is rendered possible by the same favouring circumstance.

Let us now proceed to note two or three conspicuous features of geologic evolution, remembering that in so doing we are but following out a portion of the phenomena of planetary evolution discussed in the preceding chapter. There is no demarcation in the series of phenomena, save that which we arbitrarily introduce for convenience of study and exposition. The process of integration of matter and dissipation of motion which we have just witnessed in the solar nebula as a whole, we have now to witness in that segregated portion of it which we call our earth, and we have to observe how here also indeterminate uniformity has been succeeded by determinate multiformity.

moon down to an asteroid, the differences are at bottom only differences of degree ; though the differences in result may range all the way from a world habitable by civilized men down to a mere dead ball of planetary matter. An interesting example, if it be sound, of the continuity of cosmical phenomena.

In the formation of a solid crust about the earth, there appeared the first conspicuous geologic differentiation; resulting not only in increased heterogeneity, but in increased definiteness, as the crust gradually solidified. For not only did the planet thus acquire a more definite figure, but also a more definite movement — since the solidification of the crust must have diminished the oblateness of the spheroid, thus gradually reducing the disturbance known as precession. Next with the deposit of water in the hollow places of this crust, there came the differentiation between land, sea, and atmosphere; and this differentiation became more marked as vast quantities of carbonic acid, precipitated in this primeval rain, left the atmosphere purer, and purified also the ocean by segregating its contained lime. At the same time that this vast condensation of ocean-water from preëxisting steam constituted a secondary integration attendant upon the earth's loss of molecular motion, the further thickening of the solid crust began to entail other more local integrations. As Mr. Spencer points out, while the earth's crust was still very thin, there could be neither deep oceans nor lofty mountains nor extensive continents.[1] Small islands, barren of life, washed by shallow lakes void of animate

[1] [See Spencer's *First Principles*, Part II. chap. xiv. § 109.]

existence, and covered with a dense atmosphere, loaded with carbonic acid and aqueous vapour, must have characterized the surface of our planet at this primeval epoch. But as the ever thickening crust slowly collapsed about its contracting contents, mountain ridges of considerable height could be gradually formed, islands could cohere over wider and wider spaces, and deeper basins would permit the accumulation of large bodies of water. Numerous integrations of islands into continents, and of lakes into oceans, would thus occur, making the differentiation of land and sea more distinct and definite. The integration of continents and the rise of mountain chains in different directions must have enlarged the areas of denudation, and thus rendered possible the integration of masses of detritus into extensive sedimentary strata. Differences of watershed or of river-drainage thus caused added variety to the resulting geologic formations; and these, crumbling into soil of more or less richness, afterward impressed differences upon vegetation, and thus indirectly upon animal life. Yet again, the thickening of the crust must have added to the definite heterogeneity of the surface by its effect upon volcanic phenomena. While the crust was still thin, the angry waves of liquid matter imprisoned beneath must have continually burst through volcanic vents, suddenly vaporizing large quantities of surface-water, and causing phenomena similar to those now witnessed upon Saturn and Jupiter. As the crust thickened, these volcanic agencies were more and more restrained: craters became restricted to certain localities where the crust was less thick than elsewhere, and earthquake waves began to run, as at present, along definite lines. Those well-regulated earthquake pulses which raise continents and ocean-floors at the rate of a few inches or feet per century now began to increase the definite heterogeneity of the surface. To the long rhythms of elevation and subsidence thus produced have been due countless differentiations in the directions of ocean-currents and continent-axes, in watershed, in the composition of sedimentary strata, and in climate. And to all these may be added the metamorphosis of sedimentary rocks by volcanic heat, and the seismic shoving up of strata at various angles.

All these geologic phenomena are thus seen to be classifiable as differentiations and integrations of the earth's superficial matter, caused by the continuous integration of the earth's mass with its attendant dissipation of molecular motion. We may next note that meteorologic phenomena are similarly classifiable. Before the solidification of its crust, our planet must have been comparatively homogeneous in temperature, owing to the circulation which is always maintained in masses of heated fluid. The surface portions must, however, have been somewhat cooler than the interior, and this difference would be rendered more definite by the formation of the crust, and by the subsequent separation of the ocean from the gaseous atmosphere. As the contour of land and sea became more definite and more permanent, differences in temperature between different parts of the surface must likewise have become more decided. Nevertheless the chief cause of climatic differentiations — the inclination of the earth's axis — did not begin to produce its most conspicuous effects until a later period. As long as our planet retained a great proportion of its primitive heat, there could have been little difference between winter and summer, or between the temperature at the poles and at the equator. But when the earth had lost so much heat that its external temperature began to depend chiefly upon the supply of solar radiance, then there commenced a gradual differentiation of climates. There began to be a marked difference between summer and winter, and between arctic, temperate, and tropical zones. And now also the distribution of land and sea began to produce climatic effects, owing to the fact that solar radiance is both absorbed and given out more rapidly by land than by water. Areas of the earth's surface where sea predominated began now to be distinguished from areas where land predominated, by their more equable temperature. And because the amount of solar radiance retained depends upon the density of the atmosphere, there ensued differences of climate between mountains and valleys, between table-lands and low-lying plains. Here too the increased heterogeneity was attended by increased definiteness and permanence of climatic relations. For the thermal variations, depending on the earth's rhythmic change of position with reference to the sun, set up atmospheric currents in definite directions and of tolerably regular recurrence. Sundry of these currents, swayed by the earth's rotatory momentum, became specialized as trade-winds and monsoons; while in the ocean there went on a similar specialization, as exemplified in the constant course of the Gulf Stream and other marine currents. The definiteness of the total result, as well as its heterogeneity, may be well illustrated by any map of isothermal lines, — bearing in mind, as we must, that during long periods these lines shift only within narrow limits.

Among the various portions of our earth's surface, moreover, evolution has brought about a climatic interdependence. The dependence of terrestrial temperature upon the supply and distribution of solar radiance has entailed a further dependence of local temperatures upon one another. For example the warm temperature of southern Europe is largely dependent on the hot dry winds which blow from Sahara, and which powerfully assist in melting the glaciers of the Alps. If Sahara were to be submerged — as indeed it has been at a recent epoch — these dry winds would be replaced by cooler winds charged with vapour, which would condense into snow on the Alps, and thus enlarge the glaciers already formed there, instead of melting them away. Thus the climate would be changed throughout Europe, and the direction of winds would be altered over a still larger area of the globe. If Lapland and the isthmus of Panama were to subside at the same time, so that icebergs could float through the Baltic to the coast of Prussia, while the Gulf Stream would be diverted into the Pacific Ocean, the climate of Europe might become glacial. Yet either the submergence of Greenland, or the elevation of the East Indian Archipelago into a continuous continent, would perhaps suffice to neutralize all these agencies, and restore the genial warmth. In such climatic relations we see vividly illustrated that kind of integration which brings the condition of each part of an aggregate into dependence upon the condition of all the other parts.[1]

It is now sufficiently proved that the development of the earth, like the development of the planetary system to which it belongs, has been primarily an integration of matter and dissipation of motion, and secondarily a change from indefinite homogeneity with relative isolation of parts to definite heterogeneity with relative interdependence among parts. But our survey of telluric evolution is as yet far from complete. While enough has been said concerning the redistributions of matter which have gone on over the face of the globe, nothing has been said concerning the far more wonderful and interesting redistributions of the molecular motion which the earth is continually receiving from the sun. Here, as already briefly hinted, we have the chief source of terrestrial heterogeneity. In the chapter on the Law of Evolution it was observed, as a general truth, that homogeneous forces incident upon a heterogeneous aggregate undergo differentiation and integration. We shall now find this general truth beautifully exemplified in the history of the surface

[1] [These meteorological conclusions, current at the time when Fiske wrote, would probably have been a good deal modified had he rewritten this chapter in the light of present opinion.]

of our planet. At a remote era in that history, the differentiation and integration of solar radiance began gradually to constitute the most important part of the complex process of terrestrial evolution. We have now to show how this has been done; and we shall find it desirable to introduce the subject with an inquiry into the Sources of Terrestrial Energy.

# CHAPTER VII

## THE SOURCES OF TERRESTRIAL ENERGY

AT the outset we may state broadly that all terrestrial energy is due either to direct gravitative force, or to the arrest of the centripetal motion produced by gravitative force, either in the earth or in the sun. In other words, the entire series of terrestrial phenomena is the complex product of the earth's internal heat, combined with solar radiance, and with direct gravitative force exercised by the moon and other planets.

Beginning with the smallest and least conspicuous of these sources of energy, a mere allusion will suffice for the effects wrought upon the earth by its companion planets through the medium of their tidal action upon the sun. That the phenomena of the aurora borealis, as well as the periodic variations in the position of the magnetic needle, are dependent upon the solar spots, is now a well-established doctrine; and it seems not unlikely that we shall erelong succeed in tracing out other dependences of this sort,—as is shown, for example, in Mr. Meldrum's investigation of the relations between sun-spots and rainfall. And whatever may be the final explanation of the phenomena of sun-spots, there can be little doubt that the periodicity of these phenomena is conditioned by the positions of the various planets, and especially of the giants Jupiter and Saturn. But these interrelations, though they may be much more important than is as yet suspected, need not now detain us. Such further effects as may be wrought upon the earth by polarized light sent from the other planets, and by radiance from remote stellar systems, may be left out of the account. Nor need we do more than allude to the moon's gravitative force as the chief cause of the oceanic tides, with their resultant geologic phenomena. Passing over all these circumstances, we come to the still unexpended energy represented by the earth's internal heat, concerning which we need only say that it is the cause of the geologic phenomena classed as igneous. Volcanic eruptions, earthquake shocks, elevations and subsidences of continents and ocean-floors, metamorphoses of sedimentary rocks, boiling springs, fractures of strata, and formations of metallic veins, are the various manifestations of this form of terrestrial energy.

But all these grand phenomena must be regarded as immeasurably inferior in variety and importance to those which are due to the transformation of solar radiance. These must be described with somewhat more of detail. First, with the exception of the changes wrought by the tides, all the geologic phenomena classed as aqueous are manifestations of transformed solar energy. Pulses of molecular motion proceeding from the sun are stored as reserved energy in masses of aqueous vapour raised from the sea. This energy is again partly given out as the vapour is condensed into rain and falls to the ground. The portion which remains is expended in the transfer of the fallen water through the soil, till it collects in rivulets, brooks, and rivers, and gradually descends to the ocean whence solar radiance raised it, bearing along with it divers solid particles which go to form sedimentary strata. The wind which blew these clouds into the colder regions where they consolidated into raindrops, was set in motion by solar energy, — since all winds are caused by the unequal heating of different parts of the earth's surface. Molar motion stored up in these vast masses of moving air is given out not only in the driving of clouds, but also in the raising of waves on rivers and oceans; and it is still further expended in the wearing away of shores and indentation of coast-lines which these waves effect. All the energy thus manifested by rains and rivers, winds and waves, is transformed solar radiance. And in like manner, if asked whence came the molar motion exhibited in the transfer of vast masses of sea-water along definite lines, as in the Gulf Stream and other marine currents, we may safely answer — whatever view we adopt as to the details of these movements — that it was originally due to the heat which so rarefied this water as to make it yield to the pressure of adjacent colder and denser water. And this heat came to the earth in the solar rays. Thus all movements of gaseous, liquid, and solid matter upon the earth's surface, except volcanic and tidal movements, are simply transformations of the heat which is generated by the progressive integration of the sun's mass.

But this is not the end of the matter. Our last sentence implicitly included the phenomena of life among those due to solar radiance, since the phenomena of life, whatever else they may be, are certainly included among the complex movements of gaseous, liquid, and solid matters, which occur upon the earth's surface. Let us note some of the various ways in which molecular motion, sent from the sun, is metamorphosed into vital energy.

The seed of a plant, buried in the damp earth, grows by the integration of adjacent nutritive materials, but the energy which effects this union consists in the solar undulations by which the soil is warmed. Diminish, to a certain extent, the daily supply of radiance, as in the long arctic and the short temperate winters, and the seed will refuse to grow. Though nutritive material may be at hand in abundance, there is no molecular motion which the seed can absorb. When the seed grows and shoots up its delicate green stalk, tipped with a pair of leaflets, these leaflets begin to absorb and transform those more rapid waves of the sunbeam, known as light and actinism. That the plant may continue to grow, by assimilating carbon and hydrogen, it is necessary for the leaf-molecules to decompose the carbonic acid of the atmosphere, and for the molecules of the rootlets to decompose the water which trickles through the ground. But before this can be done, the molecules of leaf and rootlet must acquire motor energy, — and this is supplied either directly or indirectly by the sunbeam. The slower undulations, penetrating the soil, set in motion the atoms of the rootlet, and enable them to shake hydrogen-atoms out of equilibrium with the oxygen-atoms which cluster about them in the compound molecules of the water. The swifter undulations are arrested by the leaves, where they communicate their motor energy to the atoms of chlorophyll, and thus enable them to dislodge adjacent atoms of carbon from the carbonic acid in which they are suspended. And these chemical motions, going on at the upper and lower extremities of the plant, disturb the equilibrium of its liquid parts, and thus inaugurate a series of rhythmical molar motions, exemplified in the alternately ascending and descending currents of sap. And lastly these molar motions, perpetually replenished from the same external sources, are perpetually expended in the molecular integration of vegetable cells and fibres. Thus all the energy stored up in the plant, both that displayed in the chemical activities of leaves and rootlets, and that which is displayed in circulation and growth, is made up of transformed sunbeams. The stately trunk, the gnarled roots, the spreading branches, the rustling leaves, the delicately tinted blossoms, and the tender fruit are all — as Moleschott no less truly than poetically calls them — the air-woven children of light.

In remote geologic ages untold millions of these solar beams were occupied in separating vast quantities of carbon from the dense atmosphere, and incorporating it in the tissues of innumerable forests. Charred by slow heat, and gradually petrified, this woody tissue became transformed into coal, which now, dug up from its low-lying beds and burned in stoves and furnaces, is compelled to give up the radiance which it long ago purloined from the sun. When placed under the engine-boiler, these transformed sunbeams are again metamorphosed into molar motions of expanding vapour, which cause the rhythmic rise and fall of the piston, and drive the running-gear of the machine shop or propel the railway train. In such wise it may be shown that the various agencies which man makes subservient to industrial purposes are nothing but variously differentiated sunbeams. The windmill is driven by atmospheric currents which the sun set in motion. The water-wheel is kept whirling by streams raised by the sun to the heights from which they are rushing down. And the steam-engine derives its energy from modern or from ancient sunbeams, according as its fires are fed by wood or by coal.

But the solar energy stored up by vegetables is given out not only in such mechanical processes, but also in the vital activities of the human beings whose needs such processes supply. The absolute dependence of animal upon vegetal life is illustrated in the familiar fact that animals cannot directly assimilate inorganic compounds. The inorganic water which we drink is necessary to the maintenance of life; but it percolates untransformed through the tissues and blood-vessels, and it quits the organism in the same chemical condition in which it entered it. And although minute quantities of the salt which we daily eat, and of the carbonates and iodides of iron which we sometimes take as tonics, may perhaps undergo transformation in the tissues, it is none the less true that the substance of our tissues can only be repaired by means of the complex albuminous molecules which solar energy originally built up into the tissues of vegetables. Herbivorous animals in each of the great classes feed directly upon vegetable fibre, and so rearrange its molecules that the resultant tissues are more highly nitrogenous than those from which they were formed. More active carnivorous animals derive from the enormous chemism latent in these nitrogenous fabrics the vital energy displayed in their rapid bounds and in their formidable grip. But the energies which imprisoned this tremendous chemical force in the complex molecules which the animal assimilates were at first supplied by sunbeams. Metamorphosed originally into the static energy of vegetable tissue, this sun-derived power is again metamorphosed into the dynamic energy which maintains the growth of the animal organism. And from the same primeval source comes the surplus energy which, after the demands of growth or repair have been satisfied, is expended in running, jumping, flying, swimming, or climbing, as well as in fighting with enemies and in seizing and devouring prey.

Besides these indirect and doubly indirect methods in which animals differentiate solar energy, there are ways in which the metamorphosis is directly effected. To cite Dr. Carpenter's conclusions, as epitomized by Mr. Spencer: "The transformation of the unorganized contents of an egg into the organized chick is altogether a question of heat: withhold heat and the process does not commence; supply heat and it goes on while the temperature is maintained, but ceases when the egg is allowed to cool. . . . In the metamorphoses of insects we may discern parallel facts. Experiments show not only that the hatching of their eggs is determined by temperature, but also that the evolution of the pupa into the imago is similarly determined, and may be immensely accelerated or retarded according as heat is artificially supplied or withheld." The phenomena thus briefly cited are to be classed under the general head of organic stimulus—and in a wide sense, one might almost say that all stimulus is the absorption of vital energy which was originally solar. Sunlight stimulates animals indirectly, as in the case of actiniæ which are made more vivacious when neighbouring sea-weed, smitten by sunbeams, pours oxygen into the water in which they move; and also in the case of hard-worked men who gain vigour from the judicious use of vegetable narcotics. The waves of motor energy which the human organism absorbs in whiffs of tobacco-smoke are but a series of pulsations of transformed sunlight.[1] But animals are also directly stimulated by the solar rays, as in the cases of insects which begin to fly and crawl in early summer, and of hibernating mammals which emerge from their retreats at the approach of warm weather. By its stimulating effect on the retina, and thence on the medulla oblongata, sunlight quickens the breathing and circulation in higher animals, and thus facilitates the repair of tissue. In the night we exhale less carbonic acid than in the daytime. Again, the stunted growth and pale sickly faces of men and women who live in coal-mines, or in narrow streets and dark cellars, are symptoms traceable to anæmia, or to a deficiency of red globules in the blood. Whence it seems not improbable that the formation of red globules, like the formation of sap in plants, may be in some way directly assisted by solar undulations.

Mysteriously allied with the vital phenomena of nutrition, innervation, and muscular action are the psychical phenomena of feeling and thought. Though (as previously hinted and as I shall hereafter endeavour to prove) the gulf

[1] As the poet-philosopher Redi says of wine: —

"Si bel sangue è un raggio acceso
Di quel Sol che in ciel vedete;
E rimase avvinto e preso
Di più grappoli alla rete."

*Bacco in Toscana*; *Opere*, tom. i. p. 2.

between the phenomena of consciousness and all other phenomena is an impassable gulf, which no future extension of scientific knowledge is likely to bridge over, it is nevertheless unquestionable both that every change in consciousness is conditioned by a chemical change in ganglionic tissue, and also that there is a discernible quantitative correspondence between the two parallel changes. Let us glance for a moment at certain facts which will serve to illustrate and justify these propositions.[1]

Those changes of consciousness which are variously classified as thoughts, feelings, sensations, and emotions cannot for a moment go on save in the presence of certain assignable physical conditions.

The *first* of these conditions is complete continuity of molecular cohesion among the parts of nerve-tissue. A nerve which is cut does not transmit sensori-motor impulses; and even where the continuity of molecular equilibrium is disturbed, without overcoming cohesion, as in a tied nerve, there is no transmission. It is in the same way that pressure on the cerebrum instantly arrests consciousness when a piece of the skull is driven in by a blow, and slowly arrests it when coma is produced by congestion

[1] [See, regarding the immediately subsequent portion of the text, Introduction, § 17, where the contrast between Spencer and Fiske, as to the topic here in question, is pointed out.]

of the cerebral arteries. Now the need for complete continuity of molecular equilibrium, both in the white and in the gray tissue, is a fact of no meaning unless a molecular rearrangement is an indispensable accompaniment of each change in consciousness.

*Secondly*, the presence of a certain amount of nutritive material in the cerebral blood-vessels is essential to every change in consciousness; and upon the quantity of material present depends, within certain limits, the rapidity of the changes. While rapid loss of blood causes fainting, or total stoppage of conscious changes, it is also true that lowered nutrition, implying deficiency of blood, retards the rate and interferes with the complication of mental processes. In a state of extreme anæmia not only does thinking go on slowly, but the manifold compounding and recompounding of conscious changes, which is implied in elaborate quantitative reasoning, cannot go on at all. Now the need for the constant presence of nutritive material is a meaningless fact unless each change in consciousness is dependent upon a molecular transfer between the nutritive material and the nerve-substance.

*Thirdly*, the maintenance of conscious changes requires the presence of certain particular materials in the blood, and the absence, in any save the smallest proportions, of certain other materials; while there are yet other materials upon the presence of which the rate and complication of conscious changes largely depend. The familiar fact that consciousness cannot for an instant continue unless oxygen is in contact with the gray tissue of the cerebrum is alone sufficient to prove that no conscious change is possible, save as the accompaniment of a chemical change. On the other hand, the presence of carbonic acid or of urea in considerable quantities retards the rate and prevents the elaboration of thinking; and in still larger quantities it puts an end to consciousness. And in similar wise the effects of alcohol, opium, and hemp, as well as of that Siberian fungus whose inhaled vapour makes a straw in the pathway look too large to be jumped over, show us most vividly how immediate is the dependence of complex mental operations upon chemical changes.

*Fourthly*, the fact that the vigour and complexity of mental manifestations bear a marked ratio to the weight of the brain, to the amount of phosphorus contained in its tissue, and to the number and intricacy of the fine sinuous creases in the gray surface of the hemispheres, shows plainly that changes in consciousness are conditioned both by the amount and by the arrangement of nerve-material.

*Fifthly*, we may see a like significance in the facts that the amount of alkaline phosphates ted by the kidneys varies with the amount ental exertion; and that emotional excitement so alters the composition of the blood that infants have been poisoned by milk secreted by their frightened or angry mothers. And lastly may be cited the beautiful experiments of Professor Lombard, in which the heat evolved by the cerebrum during the act of thinking was not only detected but measured, and found to vary according to the amount of mental activity going on.

These, though the most conspicuous, are but a few among the facts which force upon the physiologist the conclusion that there is no such thing as a change in consciousness which has not for its correlative a chemical change in nervous tissue. Hence we may the better understand the significance of familiar facts which point to a quantitative correlation between certain states of consciousness and the outward phenomena which give rise to them. A bright light, as measured by the photometer, produces a more vivid state of consciousness than a dim light. Substances which the thermometer declares to be hot are, under normal circumstances, mentally recognized as being hot. The consciousness of a sound varies in vividness with the violence of the concussions to which the sound is due. And bodies which are heavy in the balance excite in us correlative sensations of strain when we attempt to move them. Conversely the molar motions by which our states of feeling are revealed externally, have an energy proportional to the intensity of the feeling; witness the undulations indicative of pain, which, beginning with a slight twitching of the facial muscles, may end in spasmodic convulsions of the whole body. And of like import is the fact that gentle emotions, like slight electric and narcotic stimuli, agreeably quicken the heart's contractions; while violent emotions, suddenly awakened, may stop its beating as effectually as a stroke of lightning or a dose of concentrated prussic acid.

The bearings of such facts as these upon our theories of mental phenomena will be duly considered in future chapters. At present we have only to regard them as furnishing conclusive evidence that the phenomena which are subjectively known as changes in consciousness are objectively correlated with molecular motions of nerve-matter which are seen, in an ultimate analysis, to be highly differentiated forms of solar radiance. Waves of this radiance, speeding earthward from the sun at the rate of more than five hundred trillions per second, impart their motor energy to the atoms which vibrate in unison in the compound molecules of the growing grass. Cattle, browsing on this grass, and integrating portions of it with their tissues, rearrange its molecules in more complex clusters, in which the tremendous chemical energy of heat-saturated nitrogen is held in equilibrium by the aid of these metamorphosed sunbeams. Man, assimilating the nitrogenous tissues of the cow, builds up these clusters of molecules, with their stores of sun-given and sun-restrained energy, into the wondrously complex elements of white and gray nerve-tissue, which, incessantly liberating energy in decomposition, mysteriously enable him to trace and describe a portion of the astonishing metamorphosis.

When one takes a country ramble on a pleasant summer's day, one may fitly ponder upon the wondrous significance of this law of the transformation of energy. It is wondrous to reflect that all the energy stored up in the timbers of the fences and farmhouses which we pass, as well as in the grindstone and the axe lying beside it, and in the iron axles and heavy tires of the cart which stands tipped by the roadside; all the energy from moment to moment given out by the roaring cascade and the busy wheel that rumbles at its foot, by the undulating stalks of corn in the field and the swaying branches in the forest beyond, by the birds that sing in the treetops and the butterflies to which they anon give chase, by the cow standing in the brook and the water which bathes her lazy feet, by the sportsmen who pass shouting in the distance as well as by their dogs and guns, — that all this multiform energy is nothing but metamorphosed solar radiance, and that all these various objects, giving life and cheerfulness to the landscape, have been built up into their cognizable forms by the agency of sunbeams such as those by which the scene is now rendered visible. We may well declare, with Professor Tyndall, that the grandest conceptions of Dante and Milton are dwarfed in comparison with the truths which science discloses. But it seems to me that we may go farther than this, and say that we have here reached something deeper than poetry. In the sense of illimitable vastness with which we are oppressed and saddened as we strive to follow out in thought the eternal metamorphosis, we may recognize the modern phase of the feeling which led the ancient to fall upon his knees and adore — after his own crude, symbolic fashion — the invisible Power whereof the infinite web of phenomena is but the visible garment.

# CHAPTER VIII

## THE BEGINNINGS OF LIFE[1]

AMID the chaos of ideas concerning vital phenomena which prevailed until quite recent times, it was hardly strange that organisms, even of a high order of complexity, should have been supposed to be now and then directly evolved from lifeless matter, under favourable circumstances. Every reader of ancient literature will remember how Aristæus succeeded in replacing his lost swarm of bees; and the sanction thus accorded by so erudite a poet as Virgil to the popular belief in the generation of insects from putrescent meat is good evidence that the impossibility of such an occurrence had not yet been suspected, or at least had never been duly appreciated. Still more important is the testimony of Lucretius — who, as Professor Huxley well says, "had drunk deeper of the scientific spirit than any other poet of ancient or modern times except Goethe" — when he alludes to the primordial generation of plants and animals by the universal mother, Earth. It is, however, straining words some-

[1] [See Introduction, § 18.]

what beyond their usual meanings to call such speculations "scientific." They were the product of an almost total absence of such knowledge as is now called scientific. It was possible to infer that such highly organized creatures as hymenopterous insects, suddenly appearing in putrescent meat, were spontaneously generated there, only because so little was definitely known about the relations of organisms to one another and to the inorganic world. Accordingly, with the very beginnings of modern biological knowledge, and with the somewhat more cautious and systematic employment of induction characteristic of the seventeenth century, the old belief in spontaneous generation was called in question. By a series of very simple but apt experiments, in which pieces of decaying meat were protected from maggots by a gauze covering, the illustrious Redi proved, to the satisfaction of every one, that the maggots are not produced from the substance of the meat, but from eggs deposited therein by flies. So conclusive were these experiments that the belief in spontaneous generation, which had hitherto rested chiefly upon phenomena of this sort, was almost universally abandoned, and the doctrine that every living thing comes from some living thing — *omne vivum ex vivo* — received that general acceptance which it was destined to retain down to the present time. With the progress of biological knowledge, — as the complex structures and regular modes of growth of the lower animals began to be better understood, and as the microscope began to disclose the existence of countless forms of life infinitesimal in size but complicated in organization, many of which were proved to be propagated either by fission or by some kind of germination, — the doctrine *omne vivum ex vivo* became more and more implicitly regarded as a prime article of faith, and the hypothesis of spontaneous generation was not merely scouted as absurd, but neglected as unworthy of notice.

Philosophical theories conspired with observation and experiment to bring about this result. The doctrine *omne vivum ex vivo* consorted well with the metaphysical hypothesis of an *archæus*, or "vital principle," by means of which Stahl and Paracelsus sought to explain the dynamic phenomena manifested by living organisms. In those days when it was the fashion to explain every mysterious group of phenomena by imagining some entity behind it, the activities displayed by living bodies were thought to be explained when they were called the workings of a "vital principle" inherent in the living body, but distinct from it and surviving unchanged amid its manifold alterations. If a stone falls to the ground, that is a manifestation of gravitative force; but if a stream of blood comes rushing through a capillary tube, and certain compound molecules of albuminous matter are taken from it and retained by the adjacent tissue, then, according to the vitalistic theory, the "vital principle" is at work. During life this "principle" continues to work; but at death it leaves the organism, which is then given up to the mercy of physical forces. Such was the theory of life which was held by many physiologists even at a time within the recollection of persons now living; and it doubtless still survives in minds uninstructed in modern science. So long as this doctrine held undisputed sway, the belief that all life proceeds from life was not likely to be seriously impugned. For whence, save by derivation from some other "principle" like unto itself, could this mysterious "vital principle" arise? Besides all this, the Doctrine of Evolution had not yet been originated; all things were supposed to have been created at once in their present condition; and, as no need was felt of explaining scientifically the origin of the highest organisms, so there was no disposition to inquire into the origin of those lowest in the scale. A series of separate creative acts was supposed to account for the whole.

Strengthened by these metaphysical conceptions, the doctrine *omne vivum ex vivo* remained in possession of the field for two centuries.

Phenomena apparently at variance with it — such as the occasional discovery of animalcules in closed vessels — were disposed of by the hypothesis, devised by Spallanzani, that the atmosphere is full of invisible germs which can penetrate through the smallest crevices. This hypothesis is currently known as "panspermatism," or the "theory of omnipresent germs," or (less cumbrously) as the "germ-theory."

Now, as concerns the germ-theory, to which appeal is unhesitatingly made whenever the question of spontaneous generation is discussed, it must be admitted to be extremely plausible; yet we must not forget that it has never been actually demonstrated: it has not been proved that the germ-theory can do all that its advocates require it to do. It may well be the case that the air is everywhere full of germs, too small to be seen, which are capable of giving rise to all the organisms of which there is any question in the controversy about spontaneous generation; nevertheless this has not been rigorously demonstrated. The beautiful researches of Professor Tyndall have indeed proved that the atmosphere is everywhere filled with solid particles, in the absence of which it would not be luminous; and it is fair to suppose that among these particles there are always to be found some which are the germs of monads and bacteria. Still this can hardly be taken for granted;

and Dr. Bastian is right in reminding us that it is reasoning in a circle to assume the presence of germs that cannot be detected, merely because there is no other way of accounting for the presence of monads and bacteria in accordance with the doctrine of Redi.

For in all discussions concerning spontaneous generation, it should be borne in mind that the doctrine *omne vivum ex vivo* is itself on trial for its life, and cannot be summoned to the witness box. The very point to be ascertained is whether this doctrine, which is admitted to hold good in the case of all save the lowest forms of life, holds good also of these. The doctrine rests entirely upon induction; and while, in many cases, it is legitimate to infer a universal proposition from a limited induction of instances, it is not legitimate to do so in the present case. For the fact that innumerable highly specialized types of animal and vegetal life are kept up solely by generation *ex vivo* can in nowise prove that other living things, which are nearly or quite destitute of specialization, may not have their ranks recruited by a fresh evolution from not-living materials. Along with the absence of specialized structure, it may turn out that there is an absence of other characteristics once supposed to be common to all living things.

This will be more clearly understood as we proceed to consider the change which the last half-century has wrought in the theories of life with which Redi's doctrine has hitherto been implicated. The hypothesis of a "vital principle" is now as completely discarded as the hypothesis of phlogiston in chemistry, or as the Ptolemaic theory in astronomy: no biologist with a reputation to lose would for a moment think of defending it. The great discoveries concerning the sources of terrestrial energy, illustrated in the foregoing chapter, have made it henceforth impossible for us to regard the dynamic phenomena manifested by living bodies otherwise than as resulting from the manifold compounding of the molecular forces with which their ultimate chemical constituents are endowed. Henceforth the difference between a living and a not-living body is seen to be a difference of degree, not of kind, — a difference dependent solely on the far greater molecular complexity of the former. As water has properties that belong not to the gases which compose it, so protoplasm has properties that do not belong to the inferior compounds of which it is made up. The crystal of quartz has a shape which is the resultant of the mutual attractions and repulsions of its molecules; and the dog has a shape which is ultimately to be explained in the same way, save that in this case the process has been immeasurably more complex and indirect. Such, in brief, is the theory by which the vitalistic doctrine of Stahl has been replaced. Instead of a difference in kind between life and not-life, we get only a difference of degree; so that it again becomes credible that, under favouring circumstances, not-life may become life.

In the next place the overthrow of the dogma of fixity of species, and the consequent general displacement of the Doctrine of Creation by the Doctrine of Evolution, have made the scientific world familiar with the conception of the development of the more specialized forms of life from less specialized forms; and thus the development of the least specialized forms of life from the most complex forms of not-life ceases to seem absurd, and even acquires a sort of probability. And finally, the researches of geologists, showing that our earth's surface was once "melted with fervent heat," and confirming the theory of the nebular origin of our planet, have rendered it indisputable that there must once have been a time when there was no life upon the earth; so that certainly at some time or other, though doubtless not by a single step but by a number of steps, the transition from not-life to life must have been made. Hence the doctrine *omne vivum ex vivo*, as now held, means neither more nor less than that every assemblage of organic phenomena must have had as its immediate antecedent some other assemblage of phenomena capable of giving rise to it; in other words, the doctrine has become little more than a specialized corollary from the persistence of force. In the case of all save the lowest organisms, the only antecedent phenomenon capable of giving rise to the organism in question has been inductively proved to be some other organism. But in the case of the lowest organisms it is theoretically possible that the requisite antecedent may in some instances be an assemblage of unorganized materials; and it remains for induction to show whether this possibility is ever actually realized or not under existing terrestrial conditions.

Such being the modification which modern discoveries have imposed upon the doctrine *omne vivum ex vivo*, it need hardly be added that the hypothesis of spontaneous generation has undergone a no less important change. The theory that an organism which is to any extent specialized in structure can arise directly from a union of unorganized elements is ruled out of court. Such a conception, though it might be harmonized with the hypothesis of special creations, is utterly condemned by the Doctrine of Evolution. So long as it was possible to believe that enormously complex birds and mammals were somehow conjured into existence, like Aladdin's palace, in a single night, by a kind of enchantment which philosophers sought to dignify by calling it "creative fiat," it might well have seemed possible for animalcules to be spontaneously generated in air-tight flasks, or even for maggots to arise *de novo* in decaying meat. Such a view might have been logically defensible, though it was not the one which actually prevailed. But now, in face of the proved fact that thousands of years are required to effect any considerable modification in the specific structures of plants and animals, it has become impossible to admit that such specific structures can have been acquired in a moment, or otherwise than by the slow accumulation of minute peculiarities. Hence "spontaneous generation" can be theoretically admitted only in the case of living things whose grade of composition is so low that their mode of formation from a liquid solution may be regarded as strictly analogous to that of crystals. And when the case is thus stated, it becomes obvious that the phrase "spontaneous generation" is antiquated, inaccurate, and misleading. It describes well enough the crude hypothesis that insects might be generated in putrefying substances without any assignable cause; but it is not applicable to the hypothesis that specks of living protoplasm may be, as it were, *precipitated* from a solution containing the not-living ingredients of protoplasm. If such an origination of life can be proved, none will maintain that it is "spontaneous," since all will regard as the assignable cause the chemical affinity exerted between the enormously complex molecules which go to make up the protoplasm. No one speaks of "spontaneous crystallization;" and the ideas suggested by the use of the word "spontaneous" are such as to detract seriously from its availableness as a scientific term. We need a phrase which shall simply describe a fact, without any admixture of hypothesis; and we may cordially recommend as such a phrase Dr. Bastian's *archebiosis*, which, without violence to etymology, may be said to mean "life in its beginning," — or, more freely, "beginning of life."

With these preliminaries, the precise question now at issue between the believers in "spontaneous generation" and their opponents may be stated as follows: *Can archebiosis be made to occur at the present day by artificial means?* Or, to be still more accurate, *Has archebiosis actually been made to occur at the present day by artificial means?* Is it possible for the experimenter, without any assistance from life already existing, to obtain living things merely by bringing together the chemical constituents of protoplasm under suitable physical conditions? Or, granting the possibility, can it be proved that living things have actually been thus obtained? To this twofold question there are returned diverse answers. On the one hand, Dr. Bastian maintains that himself and other experimenters have actually seen archebiosis artificially brought about. On the other hand, it is likely to be maintained by most competent critics that, while there may be no good reason for denying the possibility of such a triumph of experiment, we have not yet sufficient proof that it has been really achieved.

It should not be forgotten that the decision of the more general question of the origin of life on the earth's surface does not depend upon the way in which this special controversy is decided. While it is true that the success of experiments like those of Dr. Bastian would furnish conclusive inductive proof of archebiosis, it is also true that their complete failure can in nowise be cited in evidence against the doctrine. On the one hand, the artificial production of living things, by giving us ocular testimony to the beginnings of life, would no doubt enlighten us considerably as to the physical and chemical conditions under which life originates; and it is therefore highly desirable that experimenters should be able to construct living protoplasm in the laboratory, just as it was desirable a few years ago that chemists should be able to produce such organic compounds as alcohol, sugar, and urea, — substances which until lately were thought to be, for some mysterious reason, inaccessible to human art, but which are now constructed with ease. But on the other hand, even the demonstrated impossibility of producing living things artificially would not weigh a grain in the scale against the doctrine that archebiosis may now occur, and must at some time have occurred, in the great laboratory of nature. That an evolution of organic existence from inorganic existence must at some time have taken place is rendered certain by the fact that there was once a time when no life existed upon the earth's surface. That such evolution may even now regularly take place, among such living things, for instance, as the *Bathybius* of Haeckel — a sort of albuminous jelly growing in irregular patches on the sea-bottom — is perhaps not impossible. But that such evolution has been known to take place in air-tight flasks containing decoctions of hay, and has moreover resulted in the formation of organisms like vibrios and fungus-spores, is quite another proposition, which the assertor of archebiosis is in no way bound to maintain, and with the fate of which he need not feel himself vitally concerned.

The question of "spontaneous generation," then, is but a part, and not the most essential part, of the question as to the origin of life; and we need not be surprised at finding among Dr. Bastian's opponents such an avowed evolutionist as Professor Huxley. Practically, moreover, the question at issue between the advocates of "spontaneous generation" and their antagonists is even narrower than appears from the above statement of it. As practically conducted, the dispute is confined to the question whether certain particular low forms of life — known as vibrios, bacteria, torulæ, and monads — which appear in putrescence or in fermentation, are produced by archebiosis, or are propagated from germs conveyed in the atmosphere.

If Dr. Bastian's position with reference to this question is destined to become substantiated, his work may perhaps mark an epoch in biology hardly less important than that which was inaugurated by Mr. Darwin's "Origin of Species." Unfortunately, the kind of proof which is needed for Dr. Bastian's main thesis is much more difficult, both to obtain and to estimate properly, than the kind of proof by which the theory of natural selection has been substantiated. In the latter case what was needed was some principle of interpretation which should account for the facts of the classification, embryology, morphology, and distribution of plants and animals without appealing to any other agencies than such as can be proved to be actually in operation; and it is because the theory of natural selection furnishes such a principle of interpretation that it has met with such ready acceptance from the scientific world.[1] On the other hand, the fate of the theory of archebiosis, in the shape in which it is held by Dr. Bastian, depends upon the issue of a series of experiments of extraordinary delicacy and difficulty, — experiments which are of value only when performed by scientific experts of consummate training, and which the soundest critic of inductive methods must find it perilous to interpret with confidence, unless he has had something of the training of an expert himself. For however easy it may seem to the uninitiated to shut up an organizable solution so securely that organic germs from the atmosphere cannot even be imagined capable of gaining access to it, this is really one of the most arduous tasks which an experimenter has ever had set before him. Yet to such rigour of exclusion is the inquirer forced who aims at settling the question by the direct application of the Method of Difference. And thus the question at issue is reduced to that unpromising state in which both parties to the dispute are called upon to perform the apparently hopeless task of proving a negative. When living things appear in the isolated solution, the adherents of the germ-theory are always able to point out some imaginable way in which germs might have got in. On the other hand, when

[1] I am here anticipating the argument of the two following chapters.

the panspermatists adduce instances in which no living things have been found, the believers in archebiosis are able to maintain that the failure was due, not to the complete exclusion of germs from without, but to the exclusion of some other physical condition essential to the evolution of living matter. And from this closed circle of rebutting arguments there seem at present to be no means of egress.

But in so far as the interpretation of Dr. Bastian's experiments is intended to throw light upon the beginnings of life on the earth, there is a manifest anomaly in the use of such liquid menstrua as the infusions of hay, turnip, beef, or urine, which Dr. Bastian ordinarily employs. Whatever archebiosis may occur in such media can hardly be like the process by which living things first came into existence, since the existence of the beef or turnip implies the previous existence of organisms high in the scale. The positive detection of archebiosis in these and similar menstrua will, of course, have an interest of its own; but, as Mr. Spencer well says, "a tenable hypothesis respecting the origin of organic life must be reached by some other clew than that furnished by experiments on decoction of hay and extract of beef." To meet this objection Dr. Bastian has in some experiments used only inorganic substances, like phosphate of soda, and the oxalate, tartrate, or carbonate of ammonia, in which the elements essential to the formation of protoplasm are present. Yet in such menstrua as these he believes that he has found even fungus-spores "spontaneously" generated.

The contrast here vividly brought before us draws attention to what would seem to be one of the weakest points in Dr. Bastian's theory. It is a long way from tartrate of ammonia and phosphate of soda to the spores of a fungus. It seems too long a way to be traversed in a few days or weeks amid merely the simple conditions which exist within a closed flask. A fungus-spore is not mere shapeless protoplasm. In it, as in the bacterium and the vibrio, there is a visible specialization of structure, albeit a slight specialization. These infusoria are "lowest organisms," no doubt; still they are really organisms and not merely masses of organic matter. They have forms which are more or less persistent; and in this fact is to be seen the strongest of the objections which may be urged *a priori* against Dr. Bastian's views. For organic form is a circumstance into which heredity largely enters; and where we find organisms even so simple as the jointed rods which are called vibrios, it is difficult, on theoretical grounds, not to accredit them with a regular organic parentage. Such considerations cannot weigh against a crucial experiment; but in the present state of the question they are entitled to serious attention. Dr. Bastian argues, with great ingenuity, that just as crystals, growing in a liquid menstruum, take on shapes that are determined by the mutual attractions and repulsions of their molecules, so do these colloidal bodies, which we call monads and bacteria, arising by "spontaneous generation" in liquid menstrua, take on forms that are similarly determined. The analogy, however, is not exact. I am not disposed to deny that the shape of a bacterium, or indeed of a wasp, a fish, a dog, or a man, is due, quite as much as the shape of a crystal of snow or quartz, to the forces mutually exerted on each other by its constituent molecules. But it must be remembered that in the case of an organism the direction of these forces depends, in a way not yet explained, upon the directions in which they have been exerted by ancestral organisms. In other words, a set of definite tendencies has been acquired during the slow evolution of organic life; and it may well be doubted that, even in the case of the bacterium, a tendency toward the formation of single or double nuclei can have been gained during the evolution of a single generation of individuals. For in colloidal matter, as such, there is no definite tendency toward the formation of nuclear spots, such as are seen in bacteria. It is a main characteristic of colloids, as contrasted with crystalloids, not to have any specific form. It is therefore hard to believe that, during the decomposition of some saline liquid, the freed elements not only recombine into a colloid, but even go so far as to take on the specific shape of a bacterium or vibrio. When any such succession of phenomena appears to occur, it clearly points to the ill-understood but imperative fact of heredity through a long past.

Until this difficulty is either cleared away by trustworthy deduction, or overridden by some crucial experiment, I do not think that the advocates of "spontaneous generation" can be said to have made out their case; and such an abstruse question is here opened that it is not likely soon to be settled.

For the present, in representing to ourselves how life may have originated upon the earth, we are reduced to a few most general considerations. However the question may eventually be decided as to the possibility of archebiosis occurring at the present day amid the artificial circumstances of the laboratory, it cannot be denied that archebiosis, or the origination of living matter in accordance with natural laws, must have occurred at some epoch in the past. That life has not always existed upon the earth's surface is certain; and the following considerations will show that in its first appearance there need not have been anything either sudden or abnormal.

When our earth, refusing to follow in their retreat the heavier portions of the solar nebula, began its independent career as a planet, its surface was by no means so heterogeneous as at present. We may fairly suppose that the temperature of that surface cannot have been lower than the temperature of the solar surface at the present time, which is estimated at three million degrees Fahrenheit, or some fourteen thousand times hotter than boiling water. At such a temperature there could have been no formation of chemical compounds, so that the chief source of terrestrial heterogeneity did not exist; while physical causes of heterogeneity were equally kept in abeyance by the maintenance of all things in a gaseous state. We have now to note how the mere consolidation and cooling of this originally gaseous planet must have given rise to the endless variety of structures, organic as well as inorganic, which the earth's surface now presents. The origination of life will thus appear in its proper place, as an event in the chemical history of the earth. Let us see what must have been the inevitable chemical consequences of the earth's cooling.

In a large number of cases heat is favourable to chemical union, as in the familiar instance of lighting a candle, a gas jet, or a wood fire.

The molecules of carbon and oxygen, which will not unite when simply brought into juxtaposition, nevertheless begin rapidly to unite as soon as their rates of undulation are heightened by the intense heat of the match. In like manner the phosphoric compound with which the end of the match is equipped refuses to take up molecules of atmospheric oxygen until its own molecules receive an increment of motion supplied by the arrested molar motion of the match along a rough surface. So oxygen and hydrogen do not combine when they are simply mingled together in the same vessel; but when sufficiently heated they explode and unite to form steam. In these, and in many other cases, a certain amount of heat causes substances to enter into chemical union. But it is none the less true that an enormous supply of heat implies such violent molecular undulation as to render chemical union impossible. Since the mode of attractive force known as chemism acts only at infinitesimal distances, the increase of thermal undulation, which at first only causes such a molecular rearrangement as to allow mutually attracting molecules to rush together, must at last cause such a separation of particles that chemism will be unable to act. This inference from known laws of heat is fully verified by experiment in the case of all those compounds which we can decompose by such thermal means as we have at command. Speaking generally, the most complex compounds are the most unstable, and these are the soonest decomposed by heat. The highly complex organic molecules of fibrine and albumen are often separated by the ordinary heat of a summer's day, as is witnessed in the spoiling of meat. Supersalts and double salts are decomposed at lower temperatures than simple salts; and these again yield to a less amount of heat than is required to sunder the elements of deutoxides, peroxides, etc. The protoxides, which are only one degree more complex than simple elements, withstand a still higher temperature, and several of them refuse to yield to the greatest heat which we can produce artificially. No chemist, however, doubts that a still greater heat would decompose even these.

We may thus picture to ourselves the earth's surface as at the outset composed only of uncombined elements, of free oxygen, hydrogen, nitrogen, carbon, sulphur, etc., and of iron, copper, sodium, and other metals in a state of vapour. With the lowering of this primitive temperature by radiation, chemical combinations of greater and greater heterogeneity became gradually possible. First appeared the stable binary compounds, such as water and the inorganic acids and bases. After still further lowering of temperature, some of the less stable compounds, such as salts and double salts, were enabled to appear on the scene. At a later date came the still more heterogeneous and unstable organic acids and ethers. And all this chemical evolution must have taken place before the first appearance of living protoplasm. Upon these statements we may rest with confidence, since they are immediate corollaries from known properties of matter.

When it is asked, then, in what way were brought about the various chemical combinations from which have resulted the innumerable mineral forms which make up the crust of the globe, the reply is that they were primarily due to the unhindered working of the chemical affinities of their constituent molecules as soon as the requisite coolness was obtained. As soon as it became cool enough for oxygen and hydrogen to unite into a stable compound, they did unite to form vapour of water. As soon as it became cool enough for double salts to exist, then the mutual affinities of simple binary compounds and single salts, variously brought into juxtaposition, sufficed to produce double salts. And so on throughout the inorganic world.

Here we obtain a hint as to the origin of organic life upon the earth's surface. In accordance with the modern dynamic theory of life, we are bound to admit that the higher and less stable aggregations of molecules which constitute protoplasm were built up in just the same way in which the lower and more stable aggregations of molecules which constitute a single or a double salt were built up. Dynamically, the only difference between carbonate of ammonia and protoplasm which can be called fundamental is the greater molecular complexity and consequent instability of the latter. We are bound to admit, then, that as carbonic acid and ammonia, when brought into juxtaposition, united by virtue of their inherent properties as soon as the diminishing temperature would let them, so also carbon, nitrogen, hydrogen, and oxygen, when brought into juxtaposition, united by virtue of their inherent properties into higher and higher multiples as fast as the diminishing temperature would let them, until at last living protoplasm was the result of the long-continued process.

While by following such considerations as these into greater detail the mode in which protoplasm must have arisen may by and by be partially comprehended, it is at the same time true that the ultimate mystery — the association of vital properties with the enormously complex chemical compound known as protoplasm — remains unsolved. Why the substance protoplasm should manifest sundry properties which are not manifested by any of its constituent substances we do not know, and very likely we shall never know. But whether the mystery be forever insoluble or not, it can in no wise be regarded as a solitary mystery. It is equally mysterious that starch or sugar or alcohol should manifest properties not displayed by their elements, oxygen, hydrogen and carbon, when uncombined. It is equally mysterious that a silvery metal and a suffocating gas should by their union become transformed into table-salt. Yet, however mysterious, the fact remains that one result of every chemical synthesis is the manifestation of a new set of properties. The case of living matter or protoplasm is in no wise exceptional.

In view of these considerations, it may be held that the evolution of living things is a not improbable concomitant of the cooling down of any planetary body which contains upon its surface the chemical constituents of living matter. It may perhaps turn out that we can no more reproduce in the laboratory the precise groups of conditions under which living matter was first evolved than we can obtain direct testimony as to the language and civilization of our prehistoric ancestors. But, just as it is conceded to be possible, by reasoning upon established philological principles, to obtain some trustworthy results as to the speech and culture of the prehistoric Aryans, so it must be admitted that, by reasoning upon known facts in physical science, we may get some glimpse of the circumstances which must have attended the origin of living aggregations of matter. By following out this method new light will no doubt eventually be thrown upon the past history of our planet, and a sound basis will be obtained for conjectures regarding the existence of living organisms upon some of our neighbour worlds.

In this account of the matter we have completed, so far as is needful for the purposes of this work, our exposition of the evolution of the earth. Combining the results obtained in the three foregoing chapters, we may contemplate in a single view the wonderful advance in determinate multiformity which has resulted from the integration of the earth's matter, with the accompanying dissipation of its internal motion. We have witnessed this process of evolution as manifested in geologic and meterologic phenomena; we have followed the wondrous differentiations and integrations of the molecular motion which the cooling and consolidating earth has received from the centre of our system, — and finally, from that very cooling and consolidation upon which all the foregoing phenomena are dependent, we have shown that there must naturally have ensued a progressive chemical heterogeneity, resulting at last in the genesis of compounds manifesting those properties which we distinguish as vital. Thus the continuity in cosmic evolution is grandly exhibited, and we see more clearly than ever that between the various provinces of natural phenomena there are no sharp demarcations. As the geologic development of the earth is but a specialized portion of the whole development of the solar system, — a portion which we separate from the rest and assign to a special science, solely for convenience of study; so the development of living matter is but a specialized portion of the whole development of the earth, and it is only for reasons of convenience that the formation of primeval protoplasm is assigned to a different science from that which deals with the formation of limestone or silica. Though as we advance from a lower grade of heterogeneity to a higher grade we encounter differences of property or of functional manifestation which we may broadly classify as differences of kind, the conclusion is nevertheless forced upon us that such differences of kind are ultimately reducible to differences of degree, and that at bottom there is no break whatever in the continuity of the process of Evolution.

It is not pretended, however, that these considerations fulfil all the requirements of a scientific explanation of the genesis of life. Essentially sound as I believe them to be, they do but point out the direction in which an explanation is to be sought. A complete explanation of the origin of life must include not only a statement of the general conditions under which life originated, such as I have here attempted to offer, but also a statement of the specific combination of circumstances which gave rise to such an event. If Dr. Bastian's theory of archebiosis can be inductively established, it may possibly help us to such a statement. But the considerations above adduced make it probable that a wider view of the case is needful than is implied in Dr. Bastian's researches. It seems likely that the genesis of living matter occurred when the general temperature of the earth was very different from what it is in the present day; and in order to engage in a profitable course of experimentation, we must first seek to determine, and then to reproduce if possible, all the requisite conditions associated with that general difference in temperature. Whether this can be done still remains to be seen. That the problem seems hopeless to-day might have been to Comte a sufficient reason for condemning it as vain and profitless. But the history of stellar astronomy may teach us to beware of thus hastily judging the capacity of the future by that of the present. Till within a few years it would have seemed to the wisest man incredible that we should ever be able to determine the direct approach or recession of a star. Yet, from a quarter least expected, a flood of light has been shed upon this most difficult problem. As the doe, in the old fable, keeping her sound eye landward, was at last shot by archers passing in a boat, so Nature has here been forced to render up her secret in the most unlooked-for way. Through the amazing results obtained by spectrum analysis it has turned out that the heavier difficulty has become the lighter one, and that the direct approach or recession of a star, which affords no parallax, is actually easier to measure than its thwart-motion which affords parallax! In like manner the specific solution of the problem of the origin of life need not be despaired of, nor need we wonder if it come from some quite unsuspected quarter.

Meanwhile the considerations above alleged will enable us to put the grand phenomenon of the genesis of life into its proper place among the phenomena of telluric evolution. The gulf between the geologic phase of the process and the biologic phase is so far bridged for us that we may approach the study of the latter without misgivings. In the following chapter I shall enumerate the reasons which compel us to accept the doctrine of the derivation of the more complex forms of life from less complex forms; and because of the interest which just now attaches to the question, I shall make more explicit mention of the opposing doctrine of special creations than its own merits would otherwise justify.

# CHAPTER IX

## SPECIAL CREATION OR DERIVATION?[1]

WHATEVER may be said in condemnation or approval of the method of estimating the worth of men and women by an inquiry into their pedigrees, it cannot be denied that there is often much value in such a method of estimating the worth of current ideas. Obviously a theory which was framed in a barbarous age, when men were alike unfamiliar with the conceptions of physical causation and uniformity of law and ignorant of the requirements of a valid scientific hypothesis, and which has survived until the present day, not because it has been uniformly verified by observation or deduction, but because it has been artificially protected from critical scrutiny by incorporation with a system of theological dogmas assumed to be infallible, — obviously such a theory is at the outset discredited by its pedigree. A presumption is at once raised against it, which a critical examination may indeed do away with, but which for the moment cannot fail to

[1] [See Introduction, § 18.]

have some weight with a jury of inquirers familiar with the history of human thinking. On the other hand a theory is *a priori* accredited by its pedigree when it is framed in a cultivated age by thinkers familiar alike with the special phenomena which form its subject matter and with the requirements of scientific hypothesis in general; and when, in spite of theological or sentimental prejudice, it so thrives under the most rigorous critical scrutiny that each successive decade enlists in its support a greater and greater number of the most competent investigators of nature. I do not say that such an *a priori* presumption should ever be taken as decisive in favour of any hypothesis. I say only that such considerations do have their weight, and ought to have their weight, in determining the general state of mind which we bring to the discussion of the relative merits of two theories so different in their pedigrees as are the two theories which we are now about to examine. If, with my eyes closed upon all the significant facts which bear upon the question of the origin of species, I were required to decide between two hypotheses, of which the one was framed in an age when the sky was supposed to be the solid floor of a celestial ocean, while the other was framed in an age when Lagrange and Laplace were determining the conditions of equilibrium of the solar system, I should at once decide, on general principles, in favour of the latter. And on general principles I should be quite justified in so deciding.

Happily, however, we are not called upon to render a decision, upon this or upon any other scientific question, with our eyes shut. In the present chapter we have to examine two opposing hypotheses relating to the origination of the multitudinous complex forms of animal and vegetal life which surround us. And of these two opposing hypotheses we shall find it not difficult to show that the one is discredited, not only by its pedigree and not only by the impossible assumptions which it would require us to make, but also by every jot and tittle of the scientific evidence, so far as known, which bears upon the subject; while the other is not only accredited by its pedigree, and by its requiring us to make no impracticable assumptions, but is also corroborated by all the testimony which the patient interrogation of the facts of nature has succeeded in eliciting. The former hypothesis, originating in the crude mythological conceptions of the ancient Hebrews, and uncritically accepted until the time of Lamarck and Goethe, in deference to a tradition which invested these mythological conceptions with a peculiar and unwarranted sacredness, is known as the Doctrine of Special Creations. The latter hypothesis, originating in the methodical study of the phenomena of organic life, held by a large number of biologists during the first half of the present century, and of late years accepted by nearly all, may be called the Doctrine of Derivation.

In describing the special creation hypothesis, we are confronted by an initial difficulty, due to the enormous change which has occurred in men's habits of thinking since the mythopœic age when it first gained currency. The Hebrew writer, indeed, presents us with a concrete picture of the creation of man, according to which a homogeneous clay model of the human form is, in some inconceivable way, at once transmuted into the wonderfully heterogeneous combination of organs and tissues, with all their definite and highly specialized aptitudes, of which actually living man is made up. But I suppose there are few scientific writers at the present day who would be found willing to risk their reputation for common-sense by attempting to defend such a conception. The few naturalists who still make a show of upholding the special creation hypothesis are very careful to refrain from anything like a specification of the physical processes which that hypothesis may be supposed to imply. When overtly challenged, they find it safest to shrink from the direct encounter, taking refuge in grandiloquent phrases about "Creative Will" and the "free action of an Intelligent Power," very much as the cuttle-fish extricates itself from a disagreeable predicament by hiding in a shower of its own ink. But, however commendable such phrases may be when regarded as a general confession of faith, they are much worse than useless when employed as substitutes for a scientific description of facts. They only serve to encourage that besetting sin of human thinking which accepts a play upon words as an equivalent for a legitimate juxtaposition of valid conceptions.

When translated, however, from the dialect of mythology into the dialect of science, the special creation hypothesis asserts that the untold millions of organic molecules of which an adult mammal is composed all rushed together at some appointed instant from divers quarters of the compass, and, spontaneously or in virtue of some inexplicable divine sorcery, grouped themselves into the form of an adult organism, some of them arranging themselves into infinitely complicated nerve-fibres and ganglionic cells, others into the wonderfully complex contractile tissue of muscles, while others again were massed in divers convoluted shapes, as lungs, intestines, blood-vessels, and secreting glands. Or, if a different form of statement be preferred, at one moment we have a background of landscape, with its water and its trees, its sands and its herbage, and at the next succeeding moment we have in the foreground an ox or a man, or, according to another view, a herd of oxen and a group of men, and all this without any assignable group of physical antecedents intervening! He who can believe that St. Goar, of Trèves, transformed a sunbeam into a hat-peg, or that men were once changed into werewolves by putting on an enchanted girdle, or that Joshua and Cardinal Ximenes constrained the earth to pause in its rotation, will probably find no difficulty in accepting such a hypothesis to account for the origin of men and oxen. To persons in such a stage of culture it is no obstacle to any hypothesis that it involves an assumption as to divine interposition which is incapable of scientific investigation and uninterpretable in terms of human experience. It can hardly be denied, however, that any hypothesis which involves such an assumption is at once excluded from the pale of science and relegated to the regions of mythology, where it may continue to satisfy those to whom mythologic interpretations of natural phenomena still seem admissible, but can hardly be deemed of much account by the scientific inquirer.

On the other hand, according to the doctrine of derivation, the more complex plants and animals are the slowly modified descendants of less complex plants and animals, and these in turn were the slowly modified descendants of still less complex plants and animals, and so on until we converge to those primitive organisms which are not definable either as animal or as vegetal, but which in their lowest forms are mere shreds of jelly-like protoplasm, such as the spontaneous combination of colloidal clusters of organic molecules might well be capable of originating under appropriate conditions, after the manner pointed out in the preceding chapter. The agencies by which this slow derivation of higher from lower forms has been effected are agencies such as are daily seen in operation about us; namely, individual variation, adaptation to environing circumstances, and hereditary transmission of individual peculiarities. Obviously such a hypothesis is not only highly credible in itself, since it only alleges that the growth of a complex organism from a simple globule of protoplasm, which is accomplished in every case of individual evolution, has also been accomplished during the evolution of an immensely long series of individuals; but it is also a purely scientific hypothesis, since it appeals to no agencies save such as are known to be in operation, and involves no assumptions which cannot, sooner or later, be subjected to a crucial test.

These preliminary considerations show how strong is the legitimate presumption in favour of the theory of derivation. But the case is not to be dismissed upon these summary, though forcible considerations. To the general reasons here assigned for preferring the theory of derivation to the theory of special creations, a scientific survey of the phenomena will add a number of special reasons. Four kinds of arguments in favour of the hypothesis of derivation are furnished respectively by the Classification of plants and animals, by their Embryology, by their Morphology, and by their Distribution in space and time. I shall devote the present chapter to the consideration of these four classes of arguments, reserving for the following chapter the explanation of the agencies which have been at work in forwarding the process of development.

I. The facts which are epitomized in tabular classifications of animals and plants are so familiar to us that we seldom stop to reflect upon their true significance. And in any bald statement of them which might here be made, the impression of triteness would perhaps be so strong as to prevent that significance from being duly realized, save by the student of natural history. To present in the strongest light the evidentiary value of these facts, I shall therefore have recourse to an analogous series of facts in a quite distinct science, where the significance of the classification is illustrated by the known history of the phenomena which are classified. Like the sciences of zoölogy and botany, the science of philology is preëminently a classificatory science, using the method of comparison as its chief implement of inductive research. And philology, at least so far as the study of the Aryan language is concerned, has been carried to such a high degree of scientific perfection, as regards the accuracy of its processes and the certainty of its results, that we may safely gather from it such illustrations as suit our present purpose.

The various Aryan or Indo-European languages are demonstrably descended from a single ancestral language, in the same sense in which the various modern Romanic languages are all descended from the vulgar Latin of the Western Empire. By slow dialectic variations in pronunciation, and in the use of syntactical devices for building up sentences, these languages have been imperceptibly differentiated from a single primeval language, until they are now so unlike that not one of them is intelligible, save after careful study, to the speakers of another. The minute variations, of which the cumulative result is this manifold unlikeness, have not proceeded at haphazard; but they have all along been determined by certain phonetic conditions, which have been so thoroughly generalized that philologists can now occasionally reconstruct extinct words, after a fashion somewhat similar to that in which Professor Huxley would, I presume, reconstruct an extinct animal upon seeing one of its fossilized bones or teeth.

But what now chiefly concerns us is the fact that all existing Aryan languages are the modified descendants of a common progenitor. Bearing this in mind, let us note sundry features of the classification of these languages. In the first place, it is impossible to arrange them in any linear series which will truly represent their relations to each other. In some respects Sanskrit is nearest the original type, in other respects it is Lithuanian which shows the least departure, in other respects it is Old Irish, and in yet others it is Latin. Even if we decide to make a compromise, and to begin with Sanskrit, as being on the whole the least modified of these languages, we cannot stir many steps without getting into difficulties. Suppose we say Sanskrit, Lithuanian, Old Irish, Latin, Old Slavic, Zend, Greek, Gothic, Old German. See now what we have been doing! We have indeed got old Irish and Latin close together, as they ought to be, and we have done right in putting Gothic and Old German side by side; but we have been obliged to thrust in half a dozen languages between Sanskrit and Zend, and between Latin and Greek there is a similar unseemly divorce. When we come to take in the later dialects, the confusion becomes still more hopeless. If after Sanskrit we put in Prakrit and Pali, Urdu and Bengali, and a dozen other derivatives, we must then jump back to Latin, for instance, and after following along through Italian, Spanish, French, and their sister dialects, jump back again to some ancient language. Obviously this is violating all the requirements of proper classification, which consists in putting nearest together those objects which are nearest alike.

In view of these and other kindred difficulties, philologists have long since agreed to arrange the Aryan family of languages in divergent and redivergent groups and sub-groups, along lines which ramify like the branches, branchlets, and twigs of a tree. Let us trace the pedigree of the French and English languages according to this principle of classification as elaborated by Schleicher, remembering that while other philologists have objected to some of the details of the classification,[1] all agree, and must agree, in the fundamental principle. Starting, then, from the Aryan mother-tongue, we first encounter two diverging lines of development, represented by two extinct phases of language,

1 Indeed, it is possible that the primary division should be into Eastern and Western, or European and Asiatic, rather than Northern and Southern Aryan. But the future decision of this question will not alter the principle upon which the classification is founded and which it is here cited to exemplify.

which we may call the South Aryan and North Aryan. Following the progress of the South Aryan, we find it diverging on the one hand into Indo-Iranian, and on the other hand into the parental form of the Hellenic, Italic, and Keltic languages. Neglecting the other branches, and following only the Italic, we find the divergent forms of this exemplified in Umbrian, Oscan, and Latin; and again, following the career only of the latter branch, we arrive at French and its kindred Romanic dialects. On the other hand, as we follow the North Aryan line, we find it first dividing into Teutonic and Slavo-Lettish. Neglecting the latter, we observe the Teutonic again diverging into Gothic, Old Norse, and Old German. Following only the last of these, we may observe it bifurcating into High and Low German, from the latter of which is derived the English which we speak.

Now if we take a general survey of this family-tree, we find that kindred words in languages down near the trunk resemble each other closely, while kindred words in languages high up on the twigs have often well-nigh lost all traces of their primitive family likeness. To be sure we can still recognize the English *daughter* in the Sanskrit *duhitr*, but such strong resemblances are not usual, and it is only too easy to look at a page of Sanskrit without realizing its kinship with English. But to show how the likeness diminishes as we recede from the original source, let us consider two English words — one of which has come to us by natural descent, through the North Aryan line, while the other has come to us, by adoption, from the South Aryan stock. No two words could well be more unlike than the words *pen* and *feather*. Of these the latter is a purely English word, while the former is a word we have adopted from the Latin. Now great as is the difference between these two words, it very nearly disappears when we have recourse to their Old Aryan prototypes *pata-tra* and *pat-na*. *Pat* is a word designating flight. *Pata-tra* and *pat-na* are words designating a wing, or instrument used in flying. In the course of the North Aryan development *pata-tra* becomes *fath-thra* and finally *feather*, just as *patar* becomes *father*, in accordance with a general tendency of the Teutonic toward aspirating the hard mutes of the old language; while on the other hand, in the course of the South Aryan development *pat-na* became first *pes-na* and then *pen-na*, in accordance with a general tendency of the Latin toward the assimilation of contiguous consonants. Who but a linguist, knowing the history of the words, and familiar with the general principles of phonetic change, would suspect that words apparently so distinct as *pen* and *feather* could be referred so nearly to a common origin? Or consider the French *larme* and the English *tear*. These words are demonstrably descended from the same ancestral form *dakru-ma*. But while the South Aryan form has undergone one kind of change into the Latin *lacru-ma*, and thence into the French *larme*, the North Aryan form has undergone another kind of change into the Old German *tagr*, and thence into the English *tear*.

Thus in general, as we go backward in time, we find the lines of linguistic development drawing together. Between the various Low-Dutch dialects spoken along the north coast of Germany, the differences are hardly great enough to interfere with mutual intelligibility. Again, between Portuguese and Spanish the differences are so small that one who is well acquainted with Spanish can often get the sense of many pages in a Portuguese book without having specially studied the latter language. But German and Spanish have few mutually intelligible words in common, and their differences in idioms and in structure of sentences are no less conspicuous. While it might be possible to maintain that Dutch and Platt-Deutsch, or that Portuguese and Spanish, are only dialects of the same language, no one would hesitate about calling Teutonic and Romance quite different forms of language. Yet we need only go back far enough to find the demarcation quite as obscure in the one case as in the other; for Teutonic and Romance began as the northern and southern dialects of the same Old Aryan language. In similar wise we may say that, even with the keenest linguistic instinct, it would be difficult to decipher a line of modern Persian by reason of its kinship with modern Greek; while yet it is undeniable that the Persian spoken by the officers of Xerxes was strikingly similar to the Greek spoken by Demaratos and Leonidas.

In citing this example from the phenomena of language, I do not cite it as direct testimony in favour of the theory of derivation in biology. Because *tear* and *larme* can be traced back to a common form, it does not follow that the pig and the horse have a common ancestor. Yet, while the linguistic parallel is by no means available as direct testimony in a biological question, it has nevertheless a logical value so important that zoölogists as eminent as Haeckel and philologists as profound as Schleicher have not failed to insist upon it. What we see exemplified in these linguistic phenomena is *the way in which a classification must be framed in all cases where we have to express complex genetic relationships.* We see that where a multitude of objects are associated by a common genesis, we cannot classify them in a linear series, but only in groups and sub-groups, diverging from a common trunk, like the branches and twigs of what we very aptly term a "family-tree." And on the general principles of hereditary relationship, we see that objects near the common trunk will depart less widely from the primitive ancestral type, and will therefore resemble each other more closely, than objects far up on the ends of the branches. A comparison of the different races of Aryan men would bring out the same results as the comparison of their languages. After making all allowances for the intermixture of the Aryans with divers aboriginal races in Europe and Asia, it remains generally admitted that every Aryan language is spoken by men who are predominantly Aryan in blood. Now it would be impossible to arrange Hindus, Greeks, Italians, Russians, Germans, and English in any linear series. We can only divide and subdivide, arranging them in groups that diverge and rediverge. Such must always be the case when we have to deal with phenomena due to hereditary relationship; and wherever we find a set of objects thus arranged in groups within groups, converging at the bottom and diverging at the top, we have the very strongest possible *prima facie* ground for asserting hereditary relationship.

Coming now to our main thesis, we can begin to appreciate the strength of the evidence in favour of the derivation theory, which is furnished by the classification of animals, as effected by Cuvier and Von Baer, and still further elaborated by Huxley and Haeckel. Previous to Cuvier many eminent naturalists endeavoured to arrange the animal kingdom in a series of lineally ascending groups. The illustrious Lamarck did so; and the result was that he placed oysters and snails higher up than bees and butterflies. Blainville did better, having come as near as possible to surmounting insurmountable obstacles, but he nevertheless is forced to put cirrhipeds and myriapoda above the cuttle-fish. It was a great step in advance when Cuvier showed that there are at least four distinct types of animal structure, and that no linear series can be framed; although Professor Agassiz undoubtedly transgressed the limits of scientific inquiry when he attempted to explain the coexistence of these distinct types by resuscitating from its moss-covered tomb the Platonic theory of Ideas, and impressing it into the service of natural theology. Nevertheless in his remarkable "Essay on Classification," Professor Agassiz more than atones for these metaphysical aberrations by the conclusiveness with which he shows the impossibility of making a linear classification of animals. In such a series the lowest of vertebrates, the unintelligent amphioxes, would rank above the wonderfully organized crabs, ants, and butterflies. The degraded lepidosiren would take precedence of the salmon, and the lowly organized duck-bill, as being a mammal, would be placed above the parrot and the falcon. Or if we attempted to escape these difficulties by ranking our animals in a series according to their general complexity of organization, neglecting their typical differences of structure, our whole classification would be thrown into senseless confusion. Parrots and honey-bees would be thrust in among mammals, and not only classes, but even orders, and perhaps families, of annulosa would have to be divided, to make room for intrusive echinoderms and mollusks.

In view of these difficulties, as Professor Huxley and Professor Haeckel have shown, the only feasible manner of arranging the animal kingdom is in a number of diverging or branching lines, like the boughs and twigs of a tree. Starting from the amœba and its kindred, which are neither animal nor vegetal in character, we encounter two diverging lines of development represented respectively — according to Haeckel's surmise — by those protists with harder envelopes which are the predecessors of the vegetable kingdom, and those protists with softer envelopes which are the forerunners of the more mobile animal type of organization.[1]

[1] Though I leave this sentence as it was written three years ago, it must not be understood as an unqualified endorsement of Professor Haeckel's attempt to erect a third kingdom — of

Confining our attention to animals, we meet first with the cœlenterata, including sponges, corals, and medusæ, characterized by the union of masses of amœba-like units, with but little specialization of structure or of function. Beside these lowly forms, but not immediately above any one of them, we find echinoderms starting off in one direction, worms or annuloida in a second, and molluscoida in a third. Following the first road, we stop short with echinoderms. But on the second, we find annuloid worms succeeded by articulata, or true annulosa — which re-diverge in sundry directions, reaching the greatest divergence from the primitive forms in the crabs, spiders, and ants. On the third road, we find the molluscoid worms diverging into mollusks and vertebrates. On the one hand, through the bryozoa we are

Protists — comprising such organisms as are neither distinctively animal nor vegetable. There is something to be said in behalf of such an arrangement, provided no attempt be made to draw a hard and fast line between the protistic and the two higher kingdoms; and I suppose that no follower of Haeckel is likely to make such an attempt. Since a bacterium or a vibrio is clearly not an animal, and clearly not a vegetable, while it is clearly a living thing, there would seem to be some convenience in having a region to which to assign it. I should, however, regard this "region" of protists, or lowest organisms, as not strictly a "kingdom," but rather as the indefinite border-land between the animal and vegetal worlds on the one hand and the realm of inorganic existence on the other.

gradually led to the true mollusks; while on the other hand, the tunicata, of which the ascidian or "pitcher" (the primitive "tadpole" of unscientific ridiculers of Darwinism) is the most familiar form, lead us directly to the vertebrates.[1] At first the vertebrata are all fishes, if such mol-

[1] Kowalewsky has discovered some wonderful likenesses between the embryonic development of the ascidian and that of the amphioxus or lowest known vertebrate. Of all the "missing links," the assumed absence of which is so persistently cited by the adherents of the dogma of fixity of species, the most important one would here appear to have been found; for it is a link which connects the complex and highly evolved vertebrate with a very lowly form which passes its natural existence rooted plant-like to the soil, or rather to the sea-bottom. The ascidian cannot, indeed, be regarded as typifying the direct ancestors of the vertebrata. It is a curiously aberrant and degraded form, and its own progenitors had doubtless once "seen better days." In its embryonic state it possesses a well-marked vertebral column, and it behaves in general very much as if it were going to grow to something like the amphioxus. But it afterwards falls considerably short of this mark. Already in early life its vertebræ begin to become "rudimentary" or evanescent; and when fully matured, it stops swimming about after its prey, and, striking root in the sub-marine soil, remains thereafter standing, with its broad pitcher-like mouth ever in readiness to suck down such organisms floating by as may serve for its nutriment. That vertebræ should be found in the embryo of such an animal is a most interesting and striking fact. It would seem to mark the ascidian as a retrograded offshoot of those primitive forms on the way toward assuming the vertebrate structure, of which the more fortunate ones succeeded in leaving as their representative the amphioxus.

lusk-like creatures as the amphioxus can strictly be included among fishes; but presently here too the lines begin to diverge, and we encounter reptiles and birds on the one hand, and mammals on the other, all three being related to fishes through the remarkable structures of living and extinct batrachia.

Such, as stated with crude brevity, is the classification of animals most in accordance with our present knowledge. Now from first to last, the farther we trace any one line of development, the more widely we find it diverging from other lines which originated in the same point. The higher insects and crustaceans are not at all like worms; but the myriapoda, the lower crustaceans, and the caterpillars of higher insects, are like worms. Viewed at the upper ends of the scale, the mollusks are widely different from the vertebrates; viewed at the lower end, the difference almost vanishes — the amphioxus being closely similar in structure to the ascidians, whose embryos present rudiments of a vertebral column. No two animals could well be more strikingly unlike than a wren and an elephant; yet the lowest known mammal, the Australian duck-bill, possesses many bird-like characteristics. In the man and the oak we get perhaps the widest possible amount of divergence between organisms; yet at the bottom of the animal and vegetal kingdoms we find creatures like the amœba and protococcus, which cannot be classified as either animal or vegetal, because they are as much one as the other.

Moreover, as we go back in time, we find the lines of development, now so widely distant from each other, continually drawing together. As a general rule, extinct animals are less specialized than surviving animals; and the same is true of plants. The ancient animal departed less widely from the general type of the class or sub-kingdom to which he belonged than the modern animal. The monotremata, which of all mammals are the least remote from reptiles and birds, are at the same time the oldest. In the teleosts or true fishes the differential characteristics of the vertebrate type are more strongly pronounced than in the older selachians, to which order belongs the shark. Far back in secondary times we find lizards strongly resembling fishes, and other saurian creatures which differ little from birds. Confining our attention to any particular group, such as that which embraces the ruminants and pachyderms, we find the hipparion of the Eocene epoch less specialized than either of his later kindred, the horse, ass, zebra, and quagga; while the gap between such dissimilar animals as the pig and the camel is to a great extent filled by transitional forms found in various tertiary strata.

Again, it hardly needs stating that, as we proceed from a general survey of any group of animals or plants to a survey of the sub-groups of which it is made up, we find the differences constantly growing less numerous and less fundamental. The differences between the ox and the lion are many and important — but between the various members of the order carnivora, between the lion and the wolf or the bear, the differences are less. As we descend another step, and compare lions with lynxes, jaguars, leopards, and cats, which belong to the same family, we find the points of divergence fewer and less characteristic. Between wild and domestic cats there is still less difference; while between the various breeds of the domestic cat the distinctions are limited to superficial characteristics of size, colour, and general intelligence. Hence, when classifying contemporary organisms of high development, naturalists are never in doubt as to the class or order, and but seldom as to the family; while they are not unfrequently in doubt as to the genus, and are continually disputing as to the species or variety to which a given form belongs. As we descend in the scale of development, and go back in geologic time, the determination of genera becomes more and more difficult. Doubts frequently arise with reference to family, order, and class. And at last even the sub-kingdom becomes doubtful, as is strikingly shown by the difficulty in classifying the lowly animals provisionally grouped by Cuvier as radiata, when contrasted with the ease with which naturalists distinguish the higher sub-kingdoms.

Now all this complex arrangement of organisms in groups within groups, resembling each other at the bottom of the scale and differing most widely at the top, is just the arrangement which, as we have seen, must result from genetic relationship; and upon any other theory than that of derivation it is utterly inexplicable. If each species has been separately created, no reason can be assigned for such an arrangement, — unless perchance some one can be found hardy enough to maintain that it was intended as a snare and a delusion for human intelligence. The old opponents of geology, who strove to maintain at whatever cost the scientific credit of the Mosaic myth of the creation, asserted that fossil plants and animals were created already dead and petrified, just for the fun of the thing. Manifestly those persons take a quite similar position who pretend that God created separately the horse, ass, zebra, and quagga, having previously created a beast enough like all of them to be their common grandfather. Indeed, so powerful is this argument from classification that it has always seemed to me sufficient by itself to decide the case in favour of the theory of derivation. In my own case, the facts presented in Professor Agassiz's "Essay on Classification" went far toward producing conviction before the publication of Mr. Darwin's work on the "Origin of Species," where the significance of such facts is clearly pointed out and strongly insisted upon.

II. An equally powerful argument is furnished by the embryonic development of organisms. As Von Baer long ago pointed out, the germs of all animals are at the outset exactly like each other; but in the process of development each germ acquires first the differential characteristics of the sub-kingdom to which it belongs, then successively the characteristics of its class, order, family, genus, species, and race. For example the germ-cell of a man is not only indistinguishable from the germ-cell of a dog, a chicken, or a tortoise, but it is like the adult form of an amœba or a protococcus, which are nothing but simple cells. Four weeks after conception the embryos of the man and the dog can hardly be distinguished from each other, but have become perceptibly different from the corresponding embryos of the chicken and tortoise. At eight weeks a few points of difference between the dog and the man become perceptible; the tail is shorter in the human embryo, and the cerebrum and cerebellum have become larger, relatively to the corpora quadrigemina, than in the embryo of the dog; but these differences are less striking than those which separate the two mammals on the one hand from the reptile and bird on the other. At a later stage the human embryo becomes still more unlike that of the dog, acquiring characteristics peculiar to the order of primates to which man belongs. Lastly, the fœtus of civilized man, at seven months, is entirely human in appearance, but still has not thoroughly acquired the physical attributes which distinguish the civilized man from the Australian or the negro.

On the evolution theory these phenomena are explicable as due to the integration or summing-up of adaptive processes, by which modifications slowly acquired through generations of ancestral organisms are more and more rapidly repeated in the embryos. Hence, as Professor Haeckel has elaborately proved, we must expect to find the phenomena of embryology in complete harmony with the facts of the geological succession of organisms. Observation shows that the harmony is complete; and again, unless we are to suppose that the phenomena of nature have been maliciously arranged with the express purpose of cheating us, we have no choice but to accept that harmony as proof of the truth of the evolution theory.

Kindred evidence is furnished by the well-known fact that many animals, during their fœtal life, acquire organs like those possessed by adults of allied species, but which, having no functions to discharge, are after a while absorbed or dwindle into mere rudiments. The mammalian embryo at first circulates its blood through a vascular system like the gills of fishes; afterwards this is replaced by a vascular membrane called the allantois, like the membrane which replaces gills in the development of birds and reptiles. Neither of these structures is useful to the embryo for the purpose of aerating its blood, and there is no possible explanation of their appearance in untold millions of mammals, unless we admit that they are due to inheritance from the amphibious ancestors of the mammalian class. Of like meaning are such facts as the presence of useless teeth in the jaws of fœtal whales, and in the beaks of certain embryonic birds; the rudiments of a pelvis and hind-limbs in many snakes; the wings, firmly fastened under their wing-cases, in insects which do not fly; the cæcum, or blind intestine, and the terminal vertebræ in man; and the incisor teeth in calves and other ruminants, which never cut through the gum. No explanation can be given of such phenomena, save on the theory of inheritance; for the pompous statement, which we sometimes hear, that such organs have been created "for the sake of symmetry, and in order to complete the scheme of nature," is no explanation at all. As Mr. Darwin pertinently asks, "Would it be thought sufficient to say that because planets revolve in elliptic courses round the sun, satellites follow the same course round their planets, for the sake of symmetry, and to complete the scheme of nature?" Moreover, if we were to rest content with this arbitrary assumption, we must needs confess that the symmetry of nature has been but imperfectly wrought out; for the rudimentary organs which, on this hypothesis, ought always to be present are often entirely wanting.

In this connection the history of the long exploded hypothesis of Preformation becomes very instructive. The argument is ably presented by Mr. Lewes, in a series of essays on Darwinism, which are still buried among the back numbers of the "Fortnightly Review," but which, it is to be hoped, will presently be reprinted in some more generally accessible form. Mr. Lewes calls attention to the fact that those who still profess to find it incredible that a complex organism should have been developed through long ages and through countless intermediate forms from a unicellular creature like the amœba, nevertheless find nothing incredible in the demonstrated fact that complex organisms are developed in a few weeks or months from minute homogeneous germ-cells. Now it is instructive to note that to the physiologists of a century ago the latter process of development seemed quite as incredible as the former. The process by which a structureless germ, assimilating nutriment from the blood of the parent organism, becomes gradually differentiated into such an amazingly complex creature as a man or an elephant was not at that time understood. It seemed utterly incredible that a human infant could have so recently been a simple globule of protoplasm. It was accordingly maintained that, since an infant resembles an adult in most respects save that of size, the original germ must be a minute copy of the infant. From the germ to the adult man there was no increase in complexity, there was only increase in dimensions. As a necessary consequence the germs of each generation were contained within the germs of the next preceding generation; so that in Mother Eve were contained the miniature originals of the entire human race, completely shaped in every feature, and shut up one within another, like a series of Chinese boxes!

This hypothesis now strikes us as superlatively absurd. But it has been upheld by some of the greatest biologists who have ever lived, — by Swammerdamm, Haller, Bonnet, Réaumur, and Cuvier, — and to my mind it is less grotesque than the hypothesis of special creations. But what now concerns us is the fact that the doom of the latter hypothesis is inevitably involved in the destruction of the former. For not only may it be forcibly argued "that we can no more understand the appearance of a new organism which is not the modification of some already existing organism than we can understand the sudden appearance of a new organ which is not the modification of some existing structure," but there was yet another deadly weapon lying concealed amid the mass of evidence with which Wolff and Von Baer overthrew the preformation theory. Why this roundabout method, above described, in which the germs of the higher organisms are seen to develop? Why does a mammal begin to develop as if it were going to become a fish, and then, changing its course, act as if it were going to become a reptile or bird, and only after much delay assume the peculiar characteristics of mammals? The human embryo, for example, begins with gill-like slits on each side of the neck, up to which the arteries run in arching branches, as in a fish; the heart is at first a simple pulsating chamber, like the heart of the lowest fishes; at a later period there is a movable tail considerably longer than the legs; the great toe projects sideways from the foot, like the toes of adult monkeys and apes; and, during the sixth month, the whole body is covered very thickly with hair, extending even over the face and ears, everywhere, indeed, save on the lower sides of the hands and feet, which are also bare in the adult forms of other mammals. In like manner, the tadpole of the black salamander, which is not born until it is fully formed, and which never swims, nevertheless has gills as elaborately feathered as those which, in the tadpoles of other salamanders, are destined for use. Treatises on embryology are crowded with just such facts as these. Now why is it that, in all cases, before a complex organism "can attain the structure which distinguishes it, there must be an evolution of forms which distinguish the structures of organisms lower in the series?" "None of these phases have any adaptation to the future state of the animal; many of them have no adaptation even to its embryonic state." On the hypothesis that each species of organisms was independently built up by a Divine Architect, how are we to explain these circuitous proceedings? "What," asks Mr. Lewes, "should we say to an architect who was unable, or being able was obstinately unwilling, to erect a palace except by first using his materials in the shape of a hut, then pulling it down and rebuilding them as a cottage, then adding story to story and room to room, not with any reference to the ultimate purposes of the palace, but wholly with reference to the way in which houses were constructed in ancient times? What should we say to the architect who could not directly form a museum out of bricks and mortar, but was forced to begin as if going to build a mansion; and after proceeding some way in this direction altered his plan into a palace and that again into a museum? Yet this is the sort of succession on which organisms are constructed." It is out of this very uncomfortable corner that metaphysical naturalists have sometimes attempted to slip, by gravely asserting that Nature is obliged to work tentatively! Thus we see that the habit of personifying Nature may sometimes be made to serve an argumentative purpose. When theologians are molested by uncomfortable questions concerning the existence of phenomena which seem incompatible with the perfect wisdom of an anthropomorphic Deity, they are wont to ascribe them to the Devil. It must be acknowledged that metaphysical naturalists practise a more graceful, though not a more candid, method of evasion when they erect Nature (spelled with a capital) into a person distinct from phenomena, and coolly ascribe to her the shortcomings which they dare not lay to the account of a personal Deity.

Viewed in the light of a scientific logic, this argument from embryology, like the argument from classification, seems powerful enough, when taken alone, to decide the case in favour of the derivation-theory. As already hinted, these phenomena are in general explicable by the Doctrine of Evolution. But to the special creation hypothesis they are unmanageable stumbling-blocks. Even without any profound knowledge of embryology, one may readily see that if the tadpoles of the black salamander were anciently born as tadpoles, and swam in the water, they may still retain their exquisite gills while nourished to a later stage of development in the maternal organism. But on the opposite theory the existence of these gills is meaningless.

III. The equally significant facts of morphology may be more concisely presented. Why, unless through common inheritance, should all the vertebrata be constructed on the same type? Structurally considered, man, elephant, mouse, ostrich, humming-bird, tortoise, snake, frog, crocodile, halibut, herring, and shark are but different modifications of one common form. It is a familiar fact that the arms of men and apes, the fore-legs of quadrupeds, the paddles of cetacea, the wings of birds, and the breast-fins of fishes are structurally identical, being developed from the same embryonal rudiments. Externally there is but little resemblance between the human hand and the hoof of a horse; yet anatomy shows that the horse's hoof is made up of claws or fingers firmly soldered together. Turning to the annulosa, we find that all insects and crustaceans — dragon-flies and mosquitoes as well as crabs and shrimps — are composed of just twenty segments. "What now," asks Mr. Spencer, "can be the meaning of this community of structure among these hundreds of thousands of species filling the air, burrowing in the earth, swimming in the water, creeping about among the seaweed, and having such enormous differences of size, outline, and substance that no community would be suspected between them? Why, under the down-covered body of the moth and under the hard wing-cases of the beetle, should there be discovered the same number of divisions as in the calcareous framework of the lobster?" But two answers are possible. We may either say, with the Mussulman, "it so pleased Allah, whose name be exalted;" or we may honestly acknowledge the scientific implication that such community of structure is strong evidence in favour of community of origin.

IV. The facts of geographical distribution and geological succession are likewise in complete harmony with the development theory. On the hypothesis of special creations, no good reason can be given why the extinct animals found in any geographical area should resemble, both in general structure and in special modifications, the animals which now live in the same area. Thus the fossil mammals of Australia are chiefly marsupials, allied in structure to the marsupials which now inhabit that continent; the extinct mammals of South America closely resemble living sloths, armadillos, and ant-eaters. "I was so much impressed with these facts," says Mr. Darwin, "that I strongly insisted, in 1839 and 1845, on this wonderful relationship in the same continent between the dead and the living. Professor Owen has subsequently extended the same generalization to the mammals of the Old World. We see the same law in this author's restorations of the extinct and gigantic birds of New Zealand. We see it also in the birds of the caves of Brazil. Mr. Woodward has shown that the same law holds good with sea-shells. Other cases could be added, as the relation between the extinct and living land-shells of Madeira, and between the extinct and living brackish-water shells of the Aralo-Caspian Sea."

It has indeed been urged, by upholders of the special creation hypothesis, that these striking resemblances may be explained by supposing each species to have been created in strict adaptation to the conditions of life surrounding it. That is to say, God has continued to create edentata in South America, and marsupials in Australia, because these two continents are best fitted for the comfortable maintenance respectively of edentata and of marsupials. Stubborn facts, however, are opposed to this theory of the methods of Divine working. The assumption that each species is best adapted to its own habitat is refuted by such facts as the now rapidly progressing extermination of native animals and plants in New Zealand by European organisms lately carried there. Cow-grass, thistles, dock, and white clover flourish more vigorously in New Zealand than in England, and within a few years have almost displaced the native grasses; while the native rats and flies are fast disappearing before the rats and flies imported from Europe. The assumption is still more strikingly refuted by a comparison of the forms of life which inhabit Australia with those which inhabit the southern extremities of Africa and South America. These three tracts of land are very similar in their physical conditions, and yet, as Mr. Darwin has observed, it would be impossible to point out three faunas and floras more strikingly dissimilar. If the distribution of organisms were miraculously determined in accordance with their fitness to their surrounding conditions, the fauna of South America in latitude 35° ought to resemble the fauna of Australia in the same latitude more closely than it resembles the fauna of South America in latitudes north of 25°. The case is just the reverse. Again there is no appreciable difference between the conditions of existence in the seas east and west of the isthmus of Panama; and, according to the assumption of the special-creationists, their marine faunas ought to be almost exactly alike. In fact no two marine faunas are more completely distinct. Hardly a fish, mollusk, or crustacean is common to the eastern and western shores. This is because the isthmus, though narrow, is impassable for marine organisms. On the other hand, wherever groups of organisms are not prevented by impassable barriers from spreading over wide tracts of country or of sea, we find distinct but closely allied species widely spread and living among the most diverse conditions. The inference is obvious that the population of different zoölogical and botanical areas is due to migration, and not to special creation. Where organisms have a chance to migrate, they migrate and become adapted, by slight specific changes, to the new circumstances which they encounter. But where there is a barrier between one area and another, there we find complete diversity between the inhabitants of the two areas, although there is no reason for such diversity, save the impossibility of getting across the barrier. Of like meaning is the fact that batrachians and terrestrial mammals are never found indigenous upon oceanic islands. As

Mr. Darwin observes, "the general absence of frogs and toads from oceanic islands cannot be accounted for by their physical conditions; indeed it seems that islands are peculiarly well fitted for these animals; for frogs have been introduced into Madeira, the Azores, and Mauritius, and have multiplied so as to become a nuisance. But as these animals and their spawn are known to be immediately killed by sea-water, there would be great difficulty in their transportal across the sea, and therefore on my view we can see why they do not exist on any oceanic island. But why, on the theory of creation, they should not have been created there it would be very difficult to explain." That terrestrial mammals cannot cross the sea is obvious; but bats and birds, which can fly, are found on many oceanic islands. In an admirable essay on the migrations of organisms, considered with reference to the Darwinian theory, Professor Moritz Wagner has collected many similar examples. From personal observations in North Africa, in Western Asia, in Hungary, and in America, this veteran naturalist educes the general conclusion that the limits within which allied species are found are determined by impassable natural barriers. Coleoptera with their wings fastened down under their wing-cases are specifically different on the opposite shores of small rivers; while butterflies and hymenoptera range over large tracts of inland country, but are stopped by such obstacles as the Straits of Gibraltar. On opposite sides of the Andes, the conditions of existence differ but little, while on the north and south sides of the Caucasus the difference in climate is extreme. Yet the Andes are much the more difficult to cross, and accordingly the fauna which they separate are much more unlike than the fauna separated by the Caucasus. In like manner the Galapagos Islands, situated some six hundred miles from the South American continent, possess a fauna which, with the exception of a few birds, is generically distinct from all other faunas. Yet though generically distinct, it is South American in type, and most resembles the fauna of Chili, the nearest mainland. Furthermore, among the animals living on the different islands of the group, we find specific diversity along with generic identity. So also Madeira "is inhabited by a wonderful number of peculiar land-shells, whereas not one species of sea-shell is peculiar to its shores." Similar relations are found universally to hold between the organisms which inhabit oceanic islands and those which inhabit neighbouring continents.

These facts of geographical distribution, when taken in connection with the facts of geological succession above mentioned, speak very emphatically in favour of the derivation theory. That theory affords a satisfactory explanation for this entire class of facts, while the special creation hypothesis is incompetent to explain a single one of them. They are, moreover, in perfect harmony with the prominent facts of morphology, of embryology, and of classification — so that the evidence furnished by the four classes of facts taken together becomes truly overwhelming.

When in the next chapter we come to consider the speculations and discoveries of Mr. Darwin, we shall see that the case in favour of derivation is even stronger than as here presented; for we shall see that certain agencies are unceasingly at work, with the long continuance of which the absolute stability of specific forms is incompatible. But, as between the two hypotheses of special creation and of derivation, the arguments already brought forward are far more than sufficient for a decisive verdict. The presumption raised at the outset against the Doctrine of Special Creations is even superfluously confirmed by the testimony of facts. Not only is this doctrine discredited by its barbaric origin, and by the absurd or impossible assumptions which it would require us to make, but it utterly fails to explain a single one of the phenomena of the classification, embryology, morphology, and distribution of extinct and living organisms. While, on the other hand, the Doctrine of Derivation is not only accredited by its scientific origin, and by its appealing to none but verifiable processes and agencies, but it affords an explanation for each and all of the above-mentioned phenomena.

I think we may, therefore, without further ado, consign the special creation hypothesis to that limbo where hover the ghosts of the slaughtered theories that were born of man's untutored intelligence in early times. There we may let it abide, along with the vagaries of the astrologists, the doctrine of signatures, the *archæus* of Paracelsus, the *elixir vitæ* of the alchemists, and the theory of perpetual motion. The space which we have here devoted to it is justified by the vividness with which the discussion has brought before us the contrast between mythology and science, between Anthropomorphism and Cosmism. But in the chapters which are to follow, the question of its merits or demerits will no longer concern us.

END OF VOLUME II.

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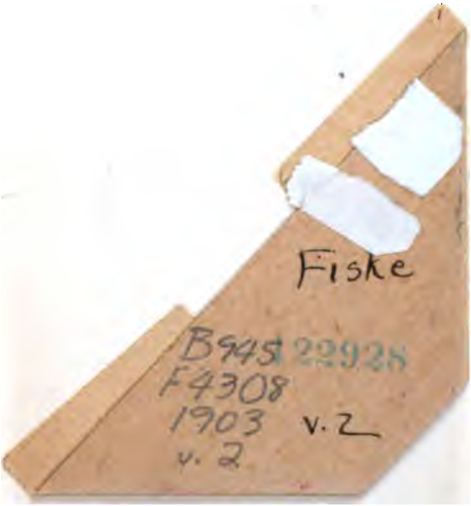
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